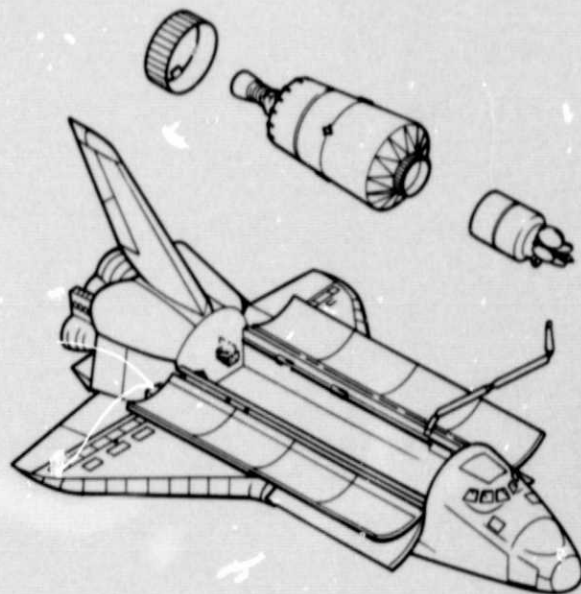


General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

REPORT NO. CASD-NAS75-017
CONTRACT NAS 8-31012



SPACE TUG/SHUTTLE INTERFACE COMPATIBILITY STUDY

FINAL REPORT

VOLUME I • EXECUTIVE SUMMARY

(NASA-CR-120650) SPACE TUG/SHUTTLE
INTERFACE COMPATIBILITY STUDY. VOLUME 1:
EXECUTIVE SUMMARY Final Report (General
Dynamics/Convair) 40 p HC \$3.75 CSCL 22B

N75-27050

Unclas
G3/18 29239

GENERAL DYNAMICS
Convair Division



REPORT NO. CASD-NAS 75-017

**SPACE TUG/SHUTTLE INTERFACE
COMPATIBILITY STUDY**

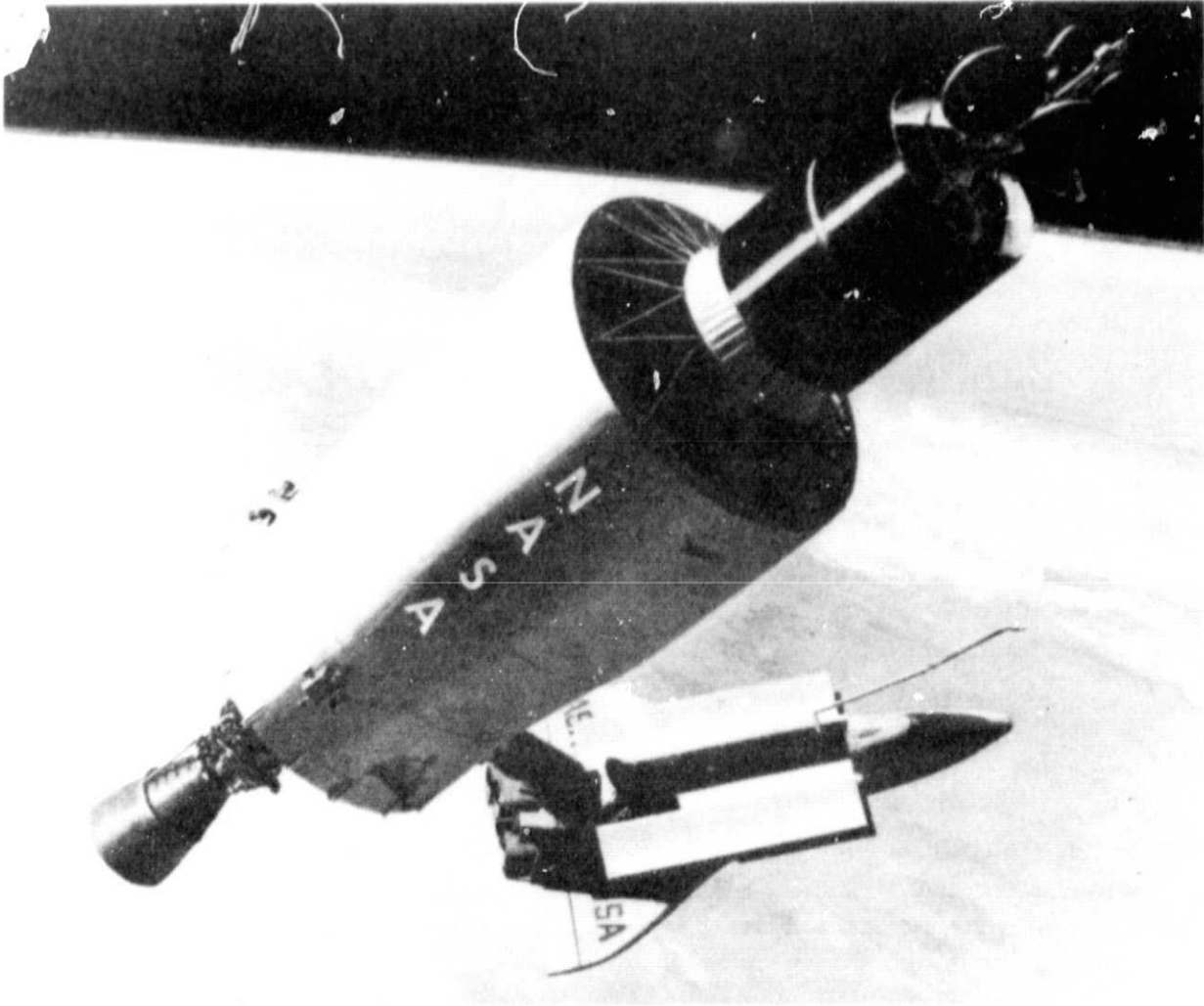
FINAL REPORT

VOLUME I ♦ EXECUTIVE SUMMARY

June 1975

Prepared for
National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

Prepared by
GENERAL DYNAMICS CONVAIR DIVISION
P.O. Box 80847
San Diego, California 92138



SUMMARY

The Space Tug/Shuttle interface compatibility study was performed to identify, evaluate, and develop Tug plus payload-to-Orbiter accommodations requirements. The study acted as the instrument by which design changes to satisfy these requirements were submitted to NASA.

Previously performed Tug-related studies did not specifically address the use or suitability of Orbiter-supplied general-purpose payload support equipment or provide detail description of any Tug-dedicated peripheral equipment. The interface study investigated these areas and supplied the lacking data.

Shuttle interfaces required for Space Tug accommodation are primarily involved with supporting and servicing the Tug during launch countdown, flight, and post-landing; deploying and retrieving the Tug on orbit; and maintaining control over the Tug when it is in or near the Orbiter. Each of these interface areas was investigated during the study to determine the best physical and operational method of accomplishing the required functions, with an overriding goal of establishing simple and flexible Orbiter interface requirements suitable for Tug, Tug payload's TUS and other cargo.

The conclusion reached as a result of these investigations was that Orbiter payload accommodations and the MSFC baseline Tug are generally interface compatible. Specific minor changes to Tug and Orbiter interfaces were identified to provide full compatibility.

The recommended system concept for supporting and deploying Tug from Orbiter employs a cylindrical load-carrying structure called a deployment adapter. The deployment adapter contains all Tug-peculiar mechanisms required for transfer of Orbiter/ground services and support of deployment, retrieval, and abort operations. Because the deployment adapter is a cylindrical structure to provide efficient axial load distribution, a rotational deployment feature is incorporated to allow Tug removal during deployment without infringing on the Orbiter cargo bay volume available for Tug payloads. By using the deployment adapter concept, Tug umbilical and deployment mechanisms can be attached and checked out before Tug installation into the Orbiter. The entire Tug, adapter, and umbilical support is installed as an autonomous unit into the Orbiter.

Major specific interface conclusions generated by study technical analysis are:

Structural Interface — The baseline Tug and its peripheral equipment should be modified to incorporate a six-point structural support arrangement. The use of

the six-point redundant support concept eliminates Tug/payload deflection and dynamic response problems associated with determinate support schemes.

Mechanical Interface — The Tug deployment adapter in conjunction with the Orbiter RMS provides excellent Tug deployment and retrieval capability.

Fluid Interface — Tug service lines are sized for simultaneous propellant dump during Orbiter abort. LH₂/LO₂ dump is safe and compatible with all abort modes. The Orbiter must provide propellant settling thrust (RCS/OMS thrusters or axial dump of Tug propellants) for low g (on-orbit) abort modes. Implementation of an Orbiter remote GH₂ vent capability is still required.

Environmental Interface — The Orbiter-supplied cargo bay prelaunch conditioning system is adequate for Tug and its payloads.

Avionics Interface — The Tug should take maximum advantage of Orbiter-supplied standard payload avionics equipment. Use of Orbiter-supplied avionics support equipment offers reduced integration costs and operational benefits.

Interface Safety — Detailed Tug/Orbiter interface safety analysis specified caution and warning philosophy, developed implementation approaches, identified 19 specific Tug caution and warning areas, and defined the crew procedures and equipment to be used in the event of a caution/warning occurrence. The incorporation of horizontal drain capability for Tug cryogenic propellants is not recommended; it results in severe Tug performance penalties and is not justified by safety hazards analyses.

Payload Services — The provision of standard umbilical panels mounted at adjustable locations throughout the cargo bay would be very desirable to supply in-bay fluid and electrical services for general Orbiter cargo and Tug payloads.

Based on these conclusions, detail definition was prepared for Tug interface equipment (deployment adapter, cable kits, and crew compartment panels) and Orbiter accommodations changes.

Twenty-two proposed Orbiter accommodations changes were submitted to encompass all the Orbiter interface recommendations resulting from interface study activity including those mentioned above. Incorporation and implementation of these revisions will provide smooth Tug/Orbiter integration and excellent interface compatibility, and is strongly recommended.

As a final study result, interface areas that would benefit from further technical analyses and predevelopment work were identified. This suggested additional effort includes structural dynamic response analyses and software design and demonstration in areas of RMS deployment/retrieval control. Tug plus deployment adapter monitor and control, and caution and warning implementation.

TABLE OF CONTENTS

Section		Page
1	INTRODUCTION	1-1
2	STUDY OBJECTIVES	2-1
3	RELATIONSHIP WITH OTHER NASA EFFORTS	3-1
4	STUDY APPROACH	4-1
5	BASIC DATA GENERATED AND SIGNIFICANT RESULTS	5-1
5.1	FUNCTIONAL INTERFACE REQUIREMENTS DEFINITION	5-1
5.2	TUG SUBSYSTEM INTERFACE ANALYSES	5-2
5.2.1	Structural Subsystem	5-3
5.2.2	Mechanical Subsystem	5-5
5.2.3	Fluid Subsystem	5-8
5.2.4	Environmental Subsystem	5-11
5.2.5	Avionics Subsystem	5-12
5.2.6	Interface Safety	5-15
5.2.7	Payload Orbiter Service Accommodations Trade	5-18
5.3	TUG/ORBITER INTERFACE REQUIREMENTS	5-20
6	STUDY LIMITATIONS	
6.1	SPACE TUG	
6.2	TUG PAYLOADS	
6.3	SHUTTLE ORBITER	-1
7	IMPLICATIONS FOR RESEARCH	7-1
7.1	TECHNOLOGY DRIVERS	7-1
7.2	TECHNICAL ANALYSES	7-1
7.3	PREDEVELOPMENT ACTIVITY	7-2
7.4	SUPPORTING RESEARCH AND TECHNOLOGY	7-2
8	SUGGESTED ADDITIONAL EFFORT	8-1

LIST OF FIGURES

Figure		Page
1-1	Space Shuttle Configuration	1-1
1-2	MSFC Baseline Tug	1-1
1 3	Tug-Related Orbiter Interface Provisions	1-2
3-1	Operational Relationship of Other Tug Studies with Interface Compatibility Study	3-2
4-1	Relationship of Interface Study Tasks	4-1
5-1	Example of Operationally Phased Functional Interface Requirements Data Sheet	5-2
5-2	Example of Tug System Functional Interface Require- ments Data Sheet	5-2
5-3	Interface Subsystem Categories	5-3
5-4	Recommended Tug Support System	5-4
5-5	Recommended Tug Fitting Configuration	5-5
5-6	Recommended Deployment Adapter Mechanisms	5-6
5-7	Procedure for Orbiter RMS Retrieval and D/A Insertion of Space Tug	5-7
5-8	Baseline Tug/Orbiter Fluid Service Accommodations	5-9
5-9	Optional Tug/Orbiter Fluid Service Accommodations	5-9
5-10	Tug Propellant Dump Parameters for RTLS Abort Trajectory	5-10
5-11	On-Orbit Abort Settling Thrust Effect on Tug Propellant Residuals	5-10
5-12	Orbiter Prelaunch Conditioning Provisions	5-12
5-13	Tug Plus Payload Purge Requirements	5-12
5-14	Diagram of Recommended Tug Avionics Interface	5-14
5-15	Tug Electrical Services Routing	5-15
5-16	Caution and Warning Implementation	5-17
5-17	Typical CRT Warning Display with Problem Solving Information	5-17
5-18	Payload Services Accommodating Choices	5-18
5-19	Recommended Services Implementation	5-19
5-20	Typical Panel Configuration and Suggested Mounting Locations	5-20
5-21	Tug/Orbiter Peripheral Equipment Description	5-22

PRECEDING PAGE BLANK NOT FILMED

LIST OF TABLES

Table	Page
3-1 Parallel MSFC Tug Studies	3-1
3-2 Overlap of Other Tug Studies with Interface Compatibility Study Interface Areas	3-2
5-1 Summary of Structural Interface Work	5-4
5-2 Summary of Mechanical Interface Work	5-6
5-3 Summary of Fluid Interface Work	5-8
5-4 Summary of Environmental Interface Work	5-11
5-5 Summary of Avionics Interface Work	5-13
5-6 Orbiter Accommodation/Tug + Payload Requirements Comparison	5-16
5-7 Summary of Interface Safety Work	5-17
5-8 Payload Service Accommodations	5-19
5-9 System Assessment of Tug/Orbiter Support/Deployment Methods	5-21
5-10 Interface Study Proposed Orbiter Accommodations Changes	5-23

SECTION 1

INTRODUCTION

The Space Transportation System flight vehicle, the Space Shuttle, consists of the major segments shown in Figure 1-1. Included as part of this transportation system is a propulsion stage called the space Tug, depicted in Figure 1-2, which is carried into low-earth orbit by the Space Shuttle in the Orbiter cargo bay. The Tug extends Shuttle capability by placing payloads into higher orbits, such as geosynchronous and interplanetary trajectories, so that more payload users may be accommodated.

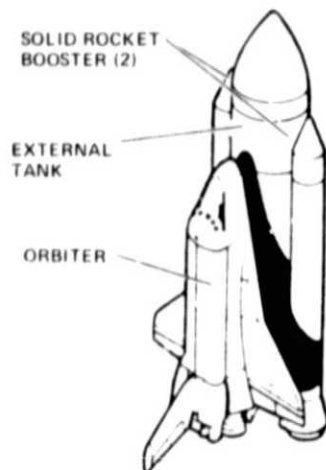


Figure 1-1. Space Shuttle Configuration

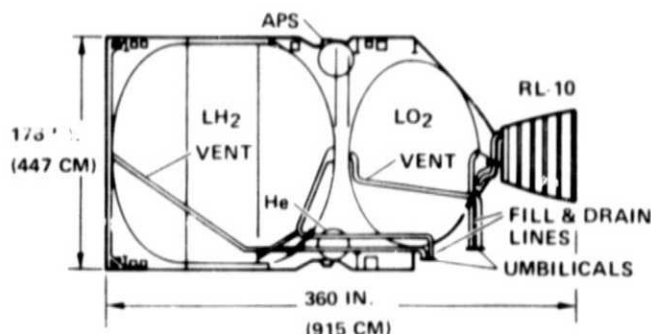


Figure 1-2. MSFC Baseline Tug

Current resource constraints preclude simultaneous development of both Space Shuttle and Tug. The government plans to have the Air Force develop an interim upper stage (IUS), to be followed by a NASA-developed full capability Tug at a later date. The IUS is planned to be operational at or near the Shuttle's initial operational capability (IOC). Although the Space Tug operational date is planned for 1983, it is important that Shuttle/Tug interface requirements be identified early so that they can be incorporated into the Shuttle. This will prevent having to constrain the Tug design due to prior Shuttle development. This advanced planning will also avoid major and costly Shuttle modification when Tug is introduced. The Space Tug/Shuttle Interface Compatibility Study was structured to compile, screen, evaluate, and recommend suitable Orbiter interface provisions for Space Tug integration. Figure 1-3 identifies typical Orbiter interfaces associated with Tug accommodation. The Shuttle/Orbiter, as currently configured, includes some general payload accommodations applicable for Space Tug, but a detailed investigation of specific interface requirements had not previously been undertaken. Tug interface requirements needed immediate definition and consideration in conjunction with other payload interface requirements for incorporation into the Shuttle Orbiter at the earliest possible date. Tug/Shuttle interface compatibility achieved early during Shuttle development will result in lower Space Transportation System program costs.

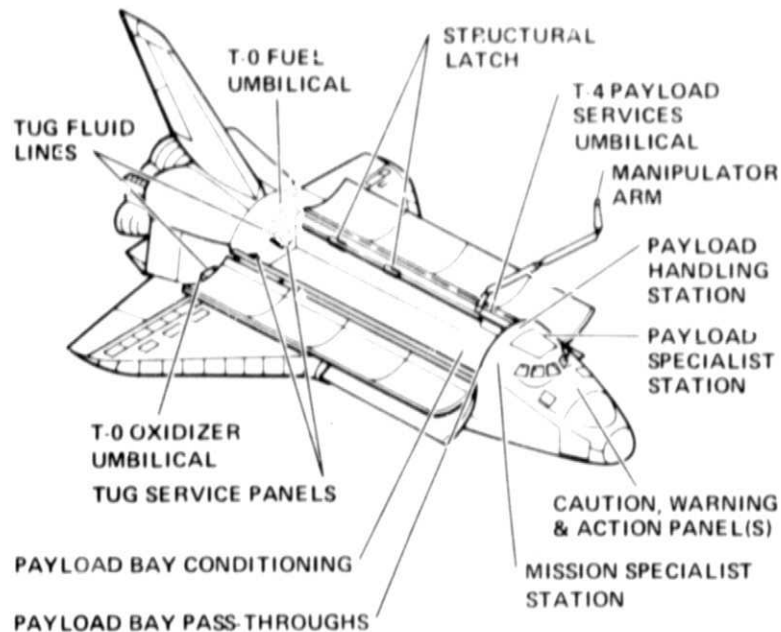


Figure 1-3. Tug-Related Orbiter Interface Provisions

The Interface Study was managed by the Tug Task Team at NASA's Marshall Space Flight Center, along with four other parallel Tug-related contracted activities. These other studies, involving ground and flight operations, payload/Tug interfaces, and Tug avionics, supported the Interface Study by generating accommodation requirements within their respective study areas.

The results of the Space Tug/Shuttle Interface Compatibility Study are contained in the four volumes of the final report. The four volumes are organized as follows:

- Volume I Executive Summary — Contains in summary form the objectives, relationship of the Interface Study to other NASA efforts, approach, data generated and significant results, limitations, research implications, and recommendations for additional effort made as a result of the study.
- Volume II Tug/Payload/Orbiter Interface Analysis — Includes the subsystem technical analysis performed, including the definition of the Tug functional interface requirements and payload service requirements, detailed analyses and trade studies of Tug/Orbiter interfaces, appropriate sensitivity studies, and special emphasis tasks.
- Volume III Tug/Payload/Orbiter Interface Requirement — Contains the system level interface assessment and the operation/physical definition of the recommended Tug/Orbiter interface, plus a description of the Orbiter and base-line Tug changes needed to accommodate the recommended interface. It also includes a comparison of IUS and Tug interface requirements, and recommends interface simulation-demonstration candidates.

Volume IV Cost Analysis — Provides the detailed study economic analysis approach, methodology, and results.

The study was arranged into six tasks, which were accomplished sequentially within the eight-month performance period:

Task 1 - Functional Interface Requirements Definition. Tug ground and flight operations were analyzed to obtain a complete accounting of all potential Tug/Orbiter interfaces, their related operations, and safety functional requirements. This analysis was conducted using baseline vehicle and operations definitions supplied by NASA-MSFC at the start of the study effort.

Task 2 - Baseline Tug Interface Analyses. Approved functional interface requirements were systematically evaluated to obtain alternative solutions and determine the optimum interface approach to satisfy each baseline Tug need. Specific payload through Tug and direct to Orbiter service requirements obtained by trade study were included. From these subsystem investigations and trade studies, detailed interface requirements for Tug/Shuttle compatibility were itemized.

Task 3 - Sensitivity Analysis. Using updated subsystem requirements from Task 2, sensitivity analyses were performed to evaluate the effect of Tug operations and design changes on Tug/Orbiter interface requirements.

Task 4 - Tug/Orbiter Interface Requirements. Results from baseline Tug interface analyses (Task 2) were assembled through a total Tug systems interface concept trade study, and a composite set of preliminary Tug/payload/Orbiter interface requirements were submitted for NASA evaluation. These proposed Orbiter accommodation revisions were submitted as recommended Level II changes. The NASA assessment included requirements reviews by MSFC and the Shuttle project.

Task 5 - Interface and Baseline Revisions. Revised interface requirements were prepared in areas where the government disapproved the initial requirements. Revisions were defined through trade studies of alternative approaches and baseline Tug changes. Since relatively few proposed changes were rejected, unused resources were applied to Tug/Orbiter interface related special emphasis tasks.

Task 6 - IUS/Tug Interface Comparison. Approved Tug requirements from Tasks 4 and 5 were compared with similar IUS requirements. Interface requirement incompatibilities were evaluated to identify and define major problems and recommend compromise solutions.

SECTION 2

STUDY OBJECTIVES

The primary objective of the Space Tug/Shuttle Interface Compatibility Study was to identify Tug and tug payload related Orbiter interface requirements, and to act as the instrument by which specific design changes to satisfy Tug requirements were submitted to NASA. Final objective achievement was accomplished by sequential satisfaction of the secondary objectives listed below:

- a. Assurance that no Tug to Orbiter functional interfaces (hardware or procedural) are missed or ignored. This objective was addressed in Study Task 1, where all functional interface requirements were derived and organized.
- b. Allocation of tug payload services and their associated interface requirements either as through Tug to Orbiter or directly from payload to Orbiter. The payload/Orbiter services accommodations trade study, performed under Study Task 2, assembled all identified tug payload service requirements, established recommended support levels, and allocated service routings. The results of this trade study, combined with Tug requirements delineated in Task 1, gave complete visibility to all combined Tug-plus-payload functional interface requirements.
- c. Continue to update requirements by exchanging information with the parallel MSFC sponsored Tug studies. The coordination objective was satisfied through data exchange meetings at Marshall Space Flight Center (MSFC), plus informal telephone conversations and meetings between members of the Interface Study team, other contractor study personnel, and NASA engineers.
- d. Determine interface requirements impacts associated with potential baseline Tug vehicle changes. Sensitivities of recommended interface solutions were investigated in Study Task 3 for the effect of baseline Tug configuration/design revisions.
- e. Obtain the best interfaces (simple, flexible, and functional) for Tug within the constraints imposed by the Orbiter. The Interface Study has evaluated a large variety of Tug/payload accommodation techniques, compared recommended implementation methods with current Orbiter provided payload services, and proposed change requests to improve these interface accommodations.
- f. Identification of additional work necessary to assure proper integration of Tug and its payload with the Shuttle Orbiter. This additional work was categorized into Simulation-Demonstration Activity involving predevelopment breadboarding or prototypes of interface systems, Technical Analyses of critical interface areas discovered during the study that are currently poorly defined or very sensitive to contemplated Orbiter operation revisions or configuration changes, and Supporting Research and Technology needed to reduce the total cost of Tug/Shuttle integration.

SECTION 3

RELATIONSHIP WITH OTHER NASA EFFORTS

The space Tug/Shuttle interface compatibility study is closely associated with other NASA programs involving Space Tug, the Space Shuttle Orbiter, and Shuttle payloads. This relationship results from the interface study's purpose, which involves the evaluation and improvement of Tug and tug payload to Orbiter interface requirements and provisions.

Space Tug Activities. Four other Tug-related studies were sponsored by Marshall Space Flight Center (MSFC) in parallel with the interface compatibility study. The study titles and their association with Tug and/or payload to Orbiter interfaces are contained in Table 3-1.

Table 3-1. Parallel MSFC Tug Studies

Study	Contractor	Contract Number
Tug Fleet and Ground Operations Schedules & Controls	Martin Marietta Corp. (MMC)	NAS8-31011
IUS/Tug-Orbiter Operations & Mission Support	International Business Machines (IBM)	NAS8-31009
Space Tug Avionics Definition	General Dynamics Convair (GDC)	NAS8-31010
IUS/Tug Payload Requirements Compatibility	McDonnell Douglas Corp (MDAC)	NAS8-31013

Each of the four parallel Tug studies overlapped the interface compatibility study to some degree. These overlaps were beneficial since they addressed particular interface problems from various operational and physical implementation points of view. Figure 3-1 depicts the operational overlaps between studies. The specific interfaces affected during these operational overlaps are identified in Table 3-2. As shown, at least two parallel Tug studies had an interest in each interface compatibility study interface area.

Orbiter Development. Since evaluation of Orbiter interface accommodations for Tug suitability is a major portion of the interface study task, the specification/implementation of Orbiter payload services is important. During performance of the interface compatibility study the horizontal flight test Orbiter vehicle was being fabricated.

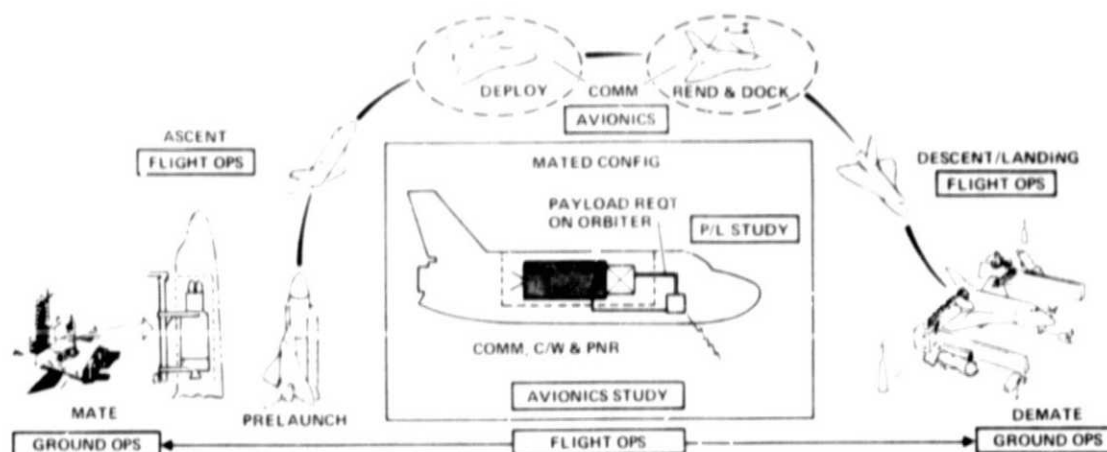


Figure 3-1. Operational Relationship of Other Tug Studies with Interface Compatibility Study

Hardware design effort was involved with producing an aerodynamically stable, structurally sound, flyable vehicle. Payload accommodations were in a "planned" rather than "implemented" mode. Continuing review by potential Shuttle users of the "Space Shuttle System Payload Accommodations" document, JSC 07700 Vol. XIV, occurred during this period, which resulted in changes and investigation of alternative interface approaches.

Other Shuttle Payload Activities. Potential Shuttle payloads other than Tug were also evaluating their Shuttle-era activity requirements concurrently with the MSFC sponsored Tug work. These efforts included DOD funded IUS studies, Jet Propulsion Laboratory (JPL) planetary spacecraft studies, European Space Lab development, and other NASA funded activities including the Space Shuttle Payload Description Activity (SSPDA). All these efforts reviewed Orbiter accommodations related to their payloads, and many processed proposed interface revisions through the MSFC payloads office and the JSC payload interface panel. These activities also resulted in potential Orbiter interface revisions.

Table 3-2. Overlap of Other Tug Studies with Interface Compatibility Study Interface Areas

INTERFACE AFFECTED	GROUND OPS	FLIGHT OPS	TUG AVIONICS	PAYLOAD REQ
	MMC	IBM	GDC	MDAC
TUG/PAYLOAD STRUCTURAL SUPPORT	X			X
PERIPHERAL EQUIPMENT MECHANISMS	X	X		
ORBITER SUPPLIED MECHANISMS	X	X		X
FLUID SERVICE UMBILICALS	X	X		X
PRELAUNCH CONDITIONING	X			X
ELECTRICAL SERVICE UMBILICALS	X	X	X	X
POWER TRANSMISSION	X	X	X	X
CAUTION & WARNING		X	X	X
RF LINK		X	X	X
SOFTWARE		X	X	
SAFETY CONSIDERATIONS	X	X	X	X
PAYLOAD CHANGEOUT	X			X
ORBITER OPERATIONS	X	X		X
ORBITER CREW EFFECTIVITY		X	X	X

SECTION 4

STUDY APPROACH

A systematic study approach was employed to identify, evaluate, and arrange for incorporation of Tug/payload interfaces in the Shuttle Orbiter. The six study technical tasks were performed sequentially as shown in Figure 4-1 to obtain detailed Tug-plus-payload-to-Orbiter interface requirements.

Tug operations were initially analyzed to identify functional interface requirements. Approaches to satisfy these requirements for the baseline Tug were then evaluated. These results, plus sensitivity analyses results evaluating the impact of baseline Tug changes on interface requirements, were assessed and a set of Tug/Orbiter interface requirements defined. The government then reviewed these requirements and any necessary interface or baseline Tug revisions were defined. Interim Upper Stage (IUS) requirements were introduced into the final technical task and compared with Tug interfaces. The process that was used to proceed through the study from functional requirements definition to IUS/Tug interface comparison, as shown in the figure, developed detailed Tug/payload interface requirements and a compatible Tug/Shuttle interface definition.

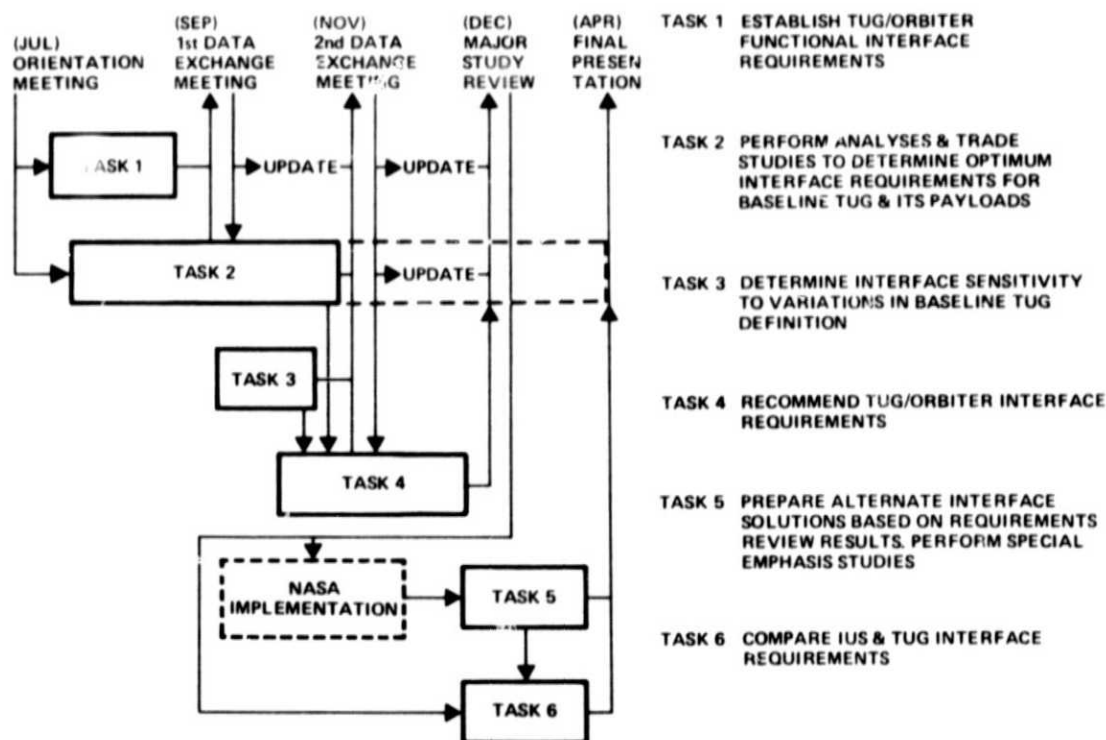


Figure 4-1. Relationship of Interface Study Tasks

SECTION 5

BASIC DATA GENERATED AND SIGNIFICANT RESULTS

Each of the six interface compatibility study tasks made some significant contribution to the overall goal of defining Tug/Payload/Orbiter interface requirements and establishing Tug peripheral equipment parameters. Three of six study tasks, however, produced a majority of the study output. Task 1 generated and compiled the Tug/Orbiter interface functional requirements for use during the subsequent study tasks. Task 2 developed and evaluated alternative methods of implementing these functional requirements by subsystem, and Task 4 assembled appropriate interface subsystems into deployment support systems, selected the best approach, and documented the Tug configuration, Orbiter interface, and operations changes required.

In the following text, important results for these three tasks are summarized. It is important to recognize that significant results documented under Tug subsystem interface analysis (Section 5.2) comprise recommendations reached as a consequence of the systems level evaluation (Section 5.3).

5.1 FUNCTIONAL INTERFACE REQUIREMENTS DEFINITION

Fundamental to a study of Tug interface requirements is the assurance that no interface function has been missed or ignored. Thus, a systematic approach was taken to identify and document all interface requirements. This approach defined functional requirements derived during Tug/Orbiter operations as they relate to determining interface needs, and organized these functional interface requirements to permit systematic evaluation within technical disciplines.

Major elements of this approach are: use of operational functional flow diagrams to identify all interface requirements, a safety and reliability assessment of identified operations and interface requirements, and a suitably organized compilation of these interface requirements.

These requirements were arranged in two sequences: operationally (mission phased) for each first level function flow block identified, as shown in Figure 5-1, and by subsystem or technical discipline to better support the interface subsystem trade studies, as shown in Figure 5-2.

The output of this task, the Functional Interface Requirements Matrix, has been documented in Report CASD/LVP 74-048-FIRM and is republished in Volume II, Section 2 of this final report. This compilation of Tug functional requirements was used during the subsystem interface analysis task to ensure that the detail implementation of Tug/Orbiter interfaces satisfied all safety and functional needs.

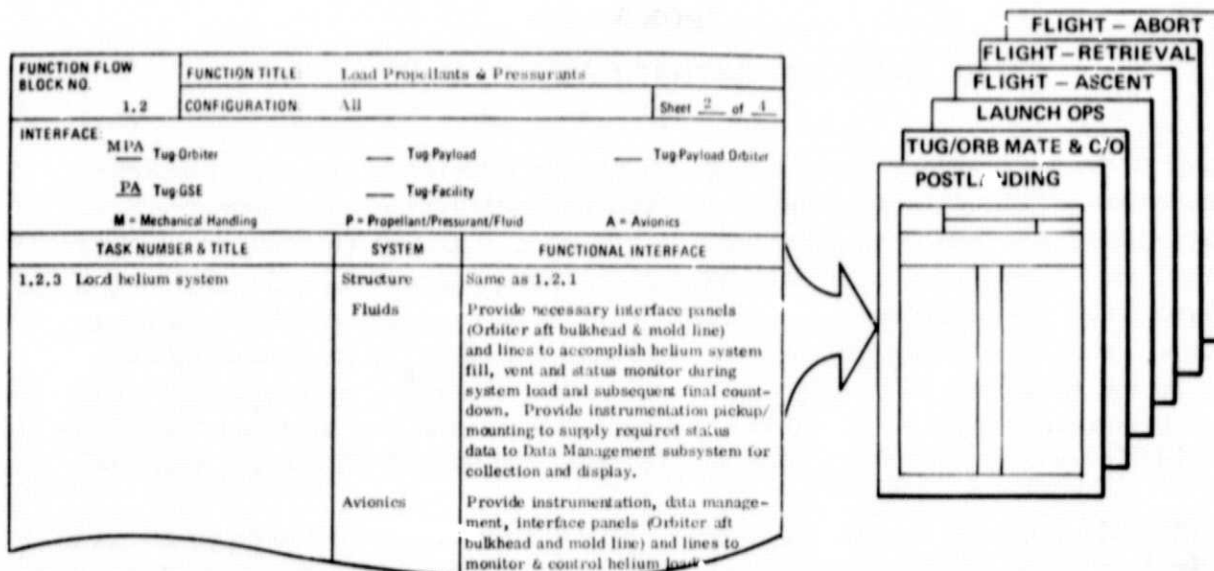


Figure 5-1. Example of Operationally Phased Functional Interface Requirements Data Sheet

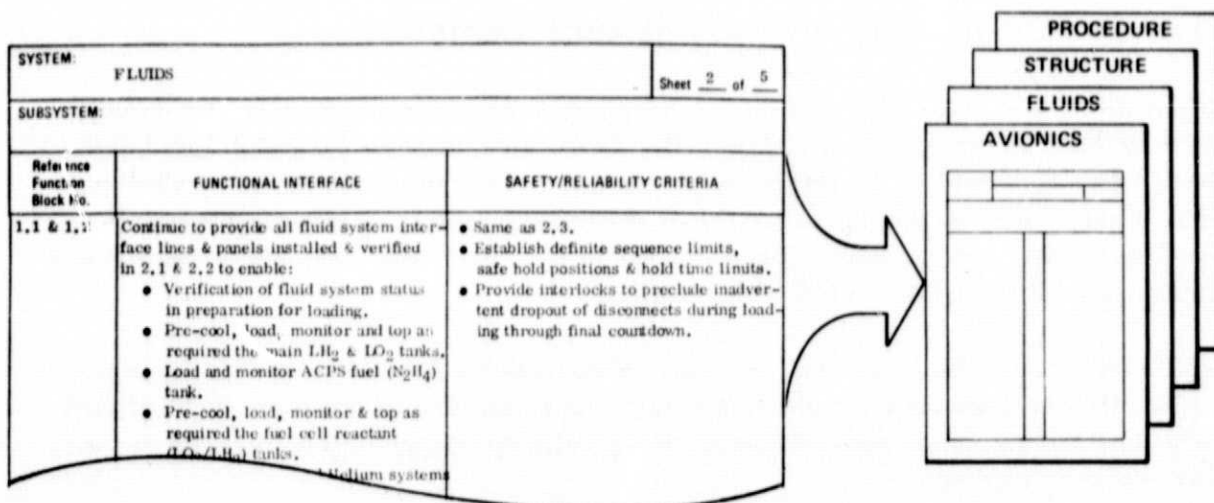


Figure 5-2. Example of Tug System Functional Interface Requirements Data Sheet

5.2 TUG SUBSYSTEM INTERFACE ANALYSES

The baseline Tug subsystem interface analyses task provided the technical data, trade studies, and screening process to translate functional interface requirements into firm, realistic Space Tug/Orbiter detailed interface requirements.

Before initiating these subsystem analyses, payload service requirements were determined. Payload needs are important since they compete with Tug for available

Orbiter services and must be considered with Tug functional requirements to determine composite interface accommodations. This activity is addressed following the presentation of interface subsystem results.

Combined Tug/Payload interface requirements were investigated on a subsystem basis to fully understand the functions of each device or operational action and thereby determine its detail interface requirements. In addition to interface analyses for the MSFC baseline Tug, alternative interface concepts were investigated. The subsystem interfaces were grouped into six categories by technical discipline as shown in Figure 5-3. The indicated accommodation(s) of major importance are presented in detail in the following text. Other interfaces included within each technical discipline have their recommendation summarized in the appropriate subsystem table.

SUBSYSTEM	ACCOMMODATION
STRUCTURAL	SUPPORT & HANDLING
MECHANICAL	DEPLOYMENT/ RETRIEVAL
FLUID	SERVICES & ABORT DUMP
ENVIRONMENTAL	CONDITIONING & PURGES
AVIONIC	MONITOR & CONTROL
SAFETY	CAUTION & WARNING

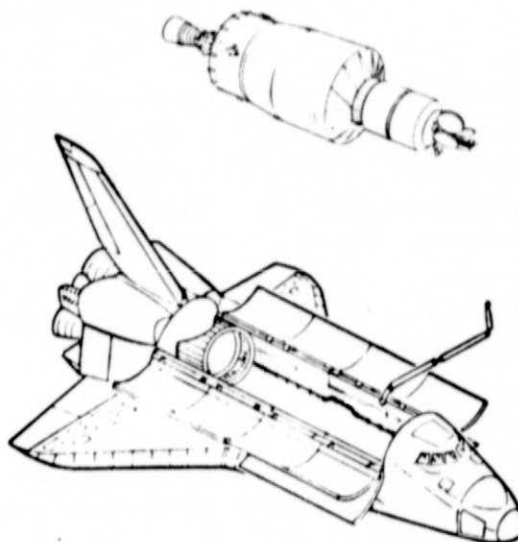


Figure 5-3. Interface Subsystem Categories

5.2.1 STRUCTURAL SUBSYSTEM. Detailed structural interface requirements were defined for each major Tug-to-Orbiter load-carrying connection. These connections occur directly between Tug and Orbiter, and through intermediate peripheral equipment such as a deployment adapter. Loading conditions imposed by the selected structural support interface concept must meet objectives of general compatibility with Orbiter payload provisions, result in tolerable Tug deflections, and impose minimum performance penalty on the Tug. Major structural support system investigations, results, and recommendations are itemized in Table 5-1. Expanded discussion includes description of the recommended Tug/Orbiter support technique and fitting design for Tug handling.

Table 5-1. Summary of Structural Interface Work

Investigation	Results	Recommendations
Reaction/Performance Analysis of 21 Support Arrangements	Reaction exceedance for determinate systems. Performance penalty for direct Tug support.	Use redundant supports. Use deployment adapter.
Finite Element Model of Tug Support System	Verification of screening parameters. Large deflections and low response frequencies for determinate systems.	Use redundant supports.
Tug Payload Support Capability	Large reaction exceedance and performance penalty for biggest payloads.	Design Tug structure to cantilever 11k lb (5k kg) payload. Separately support larger payloads from Orbiter.
Preliminary Fitting Designs and Handling Provisions	Suggested design concepts. Handling should occur at major support fittings. Current shaft grasping imposes large bending loads.	Grasp hub rather than fitting shaft.

The structural support system recommended for Tug is the six-point doubly redundant (in Z and Y directions) configuration depicted in Figure 5-4. The three aft supports (two X/Z and one Y) are located on the Tug deployment adapter (D/A). This adapter is Tug-peculiar peripheral equipment, which remains attached to the Orbiter during Tug deployment. The D/A cylindrical structure provides distribution of the point axial (X) Orbiter support loads into the Tug shell, and serves as a convenient mounting location for other support/servicing equipment including umbilical panels, dump pressurization, and interface electronics.

The redundant six-point support system recommendation results from a comparative evaluation of the six best candidates obtained from the initial screening, including both statically determinate and redundant support arrangements.

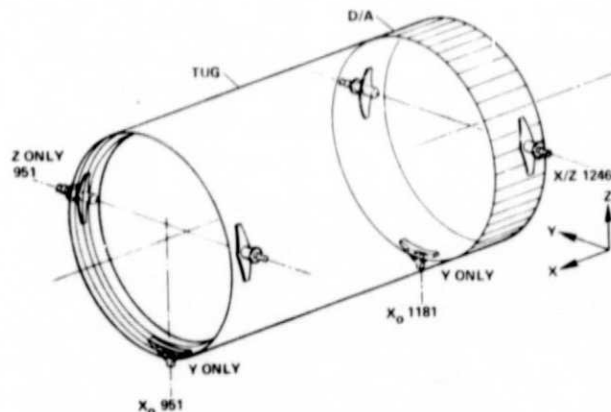


Figure 5-4. Recommended Tug Support System

The major evaluation criteria used in the selection process were: Tug Δ -weight and Δ -payload capability, Tug/Orbiter clearance loss due to Tug dynamic response, and support reaction compatibility with Orbiter capability. The selected configuration is compatible with Orbiter capability; it uses all existing primary support locations, and no reactions (including crash) exceed Orbiter capability for MSFC-developed payload/Orbiter accelerations. The six-point redundant support system is best for Tug; it results in low Tug body loads, least deflection (0.2 inch (0.5 cm) at X_0 936) least dynamic response, and excellent Tug performance.

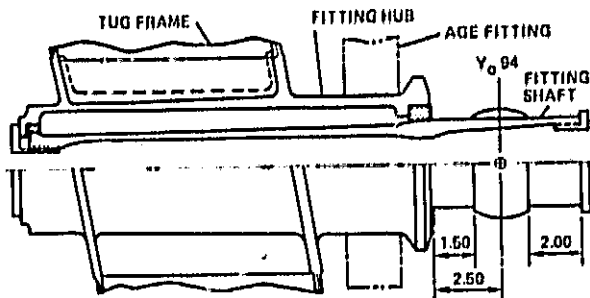


Figure 5-5. Recommended Tug Fitting Configuration

The preliminary Tug/Orbiter fitting design shown in Figure 5-5 was developed and recommended by the interface study for Tug support and handling.

This approach permits standard handling and optimized Tug (and other payload) fitting design. The concept uses an unguessed, larger-diameter hub to more efficiently carry fitting loads and to provide a location for AGE attachment. Lighter

Orbiter payloads (than Tug) would retain a specified hub outer diameter, but could adjust the material thickness and properties as required for their specific loading conditions.

5.2.2 MECHANICAL SUBSYSTEM. The Space Tug must be supported by Shuttle during launch, atmospheric flight, reentry and landing, released during deployment, and recaptured at mission completion. Mechanisms are required to engage/disengage structural latches and umbilical panels plus accomplish Tug deployment and recapture.

Mechanical subsystem investigations, results, and recommendations are summarized in Table 5-2. The recommended deployment adapter configuration shown in Figure 5-6 contains all Tug-peculiar mechanisms required for transfer of Orbiter/ground services and support of deployment, retrieval, and abort operations. Because the deployment adapter is a cylindrical structure to provide efficient axial load distribution, a rotational deployment feature is incorporated to allow Tug removal during deployment without infringing on the Orbiter cargo bay volume available for Tug payloads. Figure 5-6 shows the adapter in its rotated position. By using the deployment adapter concept, Tug umbilical and deployment mechanisms can be attached and checked out before Tug installation into Orbiter. The entire Tug, adapter, and umbilical support are installed as an autonomous unit into the Orbiter. The selected support concept shown requires umbilical panels, pivot actuators, Tug-adapter latches, alignment guides, TV cameras, and RMS attachments for interface between Tug and Orbiter.

During deployment rotation of the adapter, two struts are used to restrain the umbilical panels and provide a reaction path for the rotation actuators. These struts attach to the Tug service panels located on the Orbiter 13C7 bulkhead. Two Orbiter-supplied mechanisms are used by Tug for mission support, the longeron support latches and the remote manipulation system (RMS).

Use of the RMS to deploy and retrieve Tug was investigated. Retrieval is considered the most difficult operation: specifically attaching the RMS to Tug and repositioning and inserting the Tug into the deployment adapter. Deploying involves the same activity but with much less emphasis needed for guiding and alignment since the Tug will be moving in a direction away from the Orbiter.

Table 5-2. Summary of Mechanical Interface Work

Investigation	Results	Recommendations
Tug Pivot Location and D/A Rotation Angle	Pivot should be placed between Sta 1190 and 1260. Minimum 35 deg rotation needed for RF establishment.	Rotate at primary X/Z support at Sta 1246. Use 35 deg rotation.
Conceptual Design of Rotation Mechanism	RMS force inadequate for fitting release (friction). Position lock needed.	Use dual linear ball screw actuators mounted on one side.
Umbilical Panel Disable/Reengage Technique	Individual redundant drives for each panel are complicated.	Use D/A rotation to disconnect fluid umbilicals. C & W electrical disconnected at D/A Tug separation.
RMS Operations for Tug Deployment and Retrieval	Details of suggested Tug deployment/retrieval operation include visual aids, operator controls.	Processor support. Manual rate and jog controls. Operation envelope constraints.
RMS End Effector	Two diverse operations: Tug deployment/retrieval and contingency use.	Provide on-orbit end effector exchange capability (non-EVA).
D/A to Tug Separation Latch Conceptual Design	Uniformly distributed latches are structurally inefficient. RMS force inadequate for Tug withdrawal (friction).	Reduce 16 latches to 11; distribute about Orbiter attachment position. Provide push-away feature in latch design.

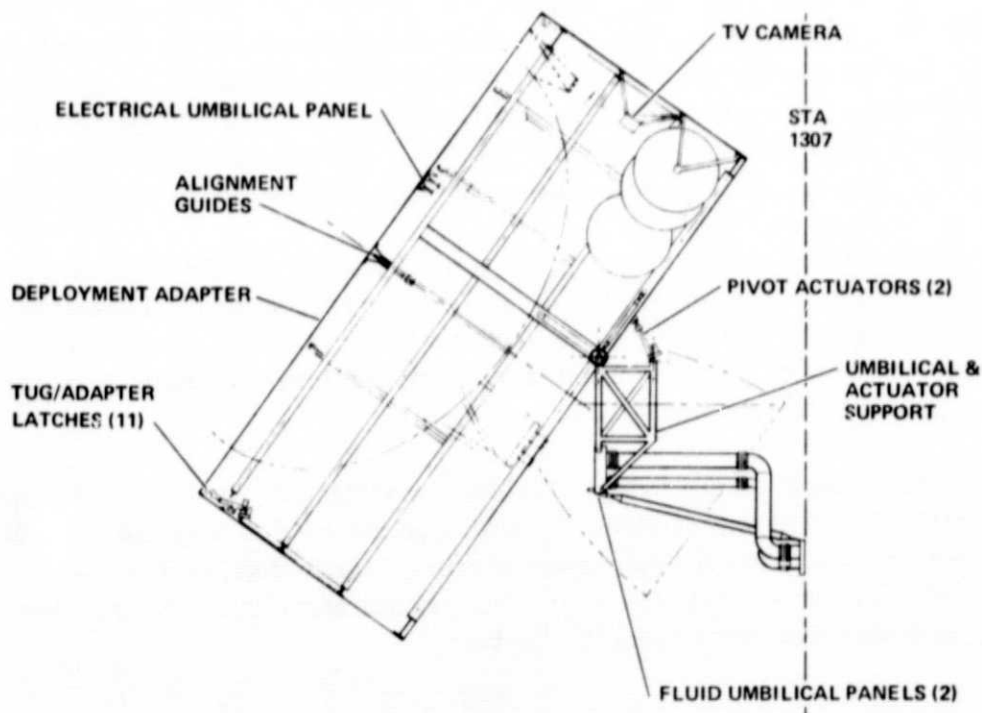


Figure 5-6. Recommended Deployment Adapter Mechanisms

The study recommended retrieval procedure depicted in Figure 5-7 is accomplished as follows: the Tug is safed, oriented and placed in an attitude hold condition prior to approach of the Orbiter. The relative Tug/Orbiter position for Tug retrieval can be observed in all areas from any two or three available viewing points, thus giving the redundancy necessary for collision avoidance. With the Tug and Orbiter positioned and stabilized, the RMS is aligned to the attachment fitting using the RMS mounted TV as primary aid. Immediately before active attachment, both the Tug and Orbiter attitude control systems are turned off so that no acceleration exists between the RMS and fitting. The RMS control capability enables end effector velocity matching to the Tug, which is accomplished with man-in-the loop computer control. Attachment is obtained by extending the end effector until a proximity switch signals contact to cause grasping of the Tug. The Orbiter attitude control is reactivated, and the Tug ACS is safed for mission termination.

For translating the Tug and insertion into the deployment adapter, direct vision through the bulkhead window and TV vision from the deployment adapter camera are used to ensure proper alignment. The combined RMS tip position error, angular error, and end effector attachment error can be monitored through the adapter TV as the Tug approaches. Manual input by the manipulator operator to the computer-controlled Tug insertion program enables RMS positioning of Tug to center the Tug's docking

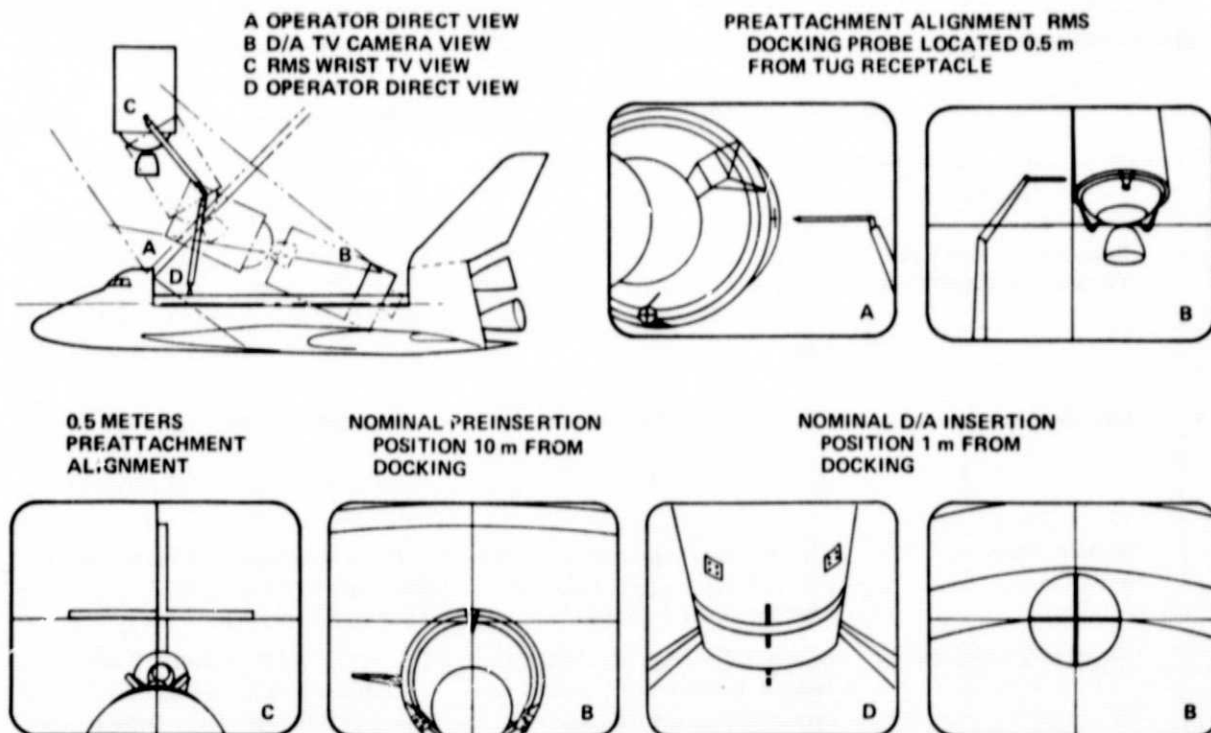


Figure 5-7. Procedure for Orbiter RMS Retrieval and D/A Insertion of Space Tug

target. The remaining significant alignment error is around the Tug centerline in roll. With the target centered, the alignment stripe visible through the window gives indication of roll positioning.

Preprogrammed computer control with manual override enables Tug installation into the deployment adapter in minimum time with small effort. By programming a time-motion acceptable for moving a maximum weight Tug/payload, a fixed procedure can be used on all mission configurations to decrease crew training and software changes.

5.2.3 FLUID SUBSYSTEM. Tug fluid functional requirements must be satisfied through the use of Orbiter-mounted Tug fluid service equipment with lines 15 to 18 feet (4.0 to 5.5 m) long connecting ground/Orbiter and Orbiter/Tug interface panels. The fluid interface analysis task determined the optimum number, size, and sharing of service line functions and developed the detail specifications (pressure, flow, temperature, control requirements) in sufficient detail to establish design requirements for the Orbiter-mounted equipment (transfer lines, disconnects). Table 5-3 summarizes the investigations and significant output.

Figure 5-8 identifies the fluid service line interface requirements for the Space Tug. It depicts the baseline configuration in which all service lines (except the GO_2 vent) pass through the 1307 bulkhead and, with the exception of the LH_2 flight vent, the T-O panel. Line diameters and number of interfaces at the deployment adapter/Tug flight disconnect panels, the 1307 panels, and the T-O panels are identified.

Table 5-3. Summary of Fluid Interface Work

Investigation	Results	Recommendations
Determine Fluid Line Physical Requirements	Optimized dimensions and identified interface parameters. Need for separate LO_2 topping line.	Ten service lines needed for baseline concepts. Eleven service lines required for side panel option. No appreciable Tug impact.
Control Requirements	GH_2 vent must be transferred from T-O (prelaunch) to remote location for ascent.	Place vent selection valve in D/A — two Orbiter I/F. Tug dump under Tug control (Orbiter initiate).
Service Panel Locations	1307 panel locations compatible with D/A-Tug umbilicals and minimum line lengths.	1307 panels should not be moved. Side panels for LH_2 and LO_2 dump are acceptable.
Abort Requirements	Dump lines sized for RTLS (300 second dump) abort. Initial and final settling thrust required from Orbiter for low g dump. Small settling thrust required for full duration of low g dump.	5.0 LH_2 4.0 LO_2 through T-O. 4.8 LH_2 4.0 LO_2 through side. Low g dump initiation — 3600 lb thrust for 20 sec, termination 3600 lb thrust for 50 sec. Use axially dumped Tug propellants \approx 360 lb thrust.

Figure 5-9 shows an alternative fluid line routing concept currently being considered by the Orbiter in which the abort dump lines and leakage vents exit through the Orbiter mid-body (no 1307 or T-O interfaces). Diameters required for the dump lines in the alternative concept are approximately the same as baseline; but the fill and drain lines, which pass through the Orbiter aft fuselage, are reduced to 2 inches (5.1 cm) diameter. Tug-related weight differences and performance deltas between the baseline and the optional configuration are insignificant. Generally, the Tug is relatively insensitive to the fluid service routine approach employed by the Orbiter, and either the baseline or the option shown are acceptable to Tug.

One alternative proposed, but not shown in Figure 5-9, is routing the inflight GH_2 vent (Code 3) to the cargo bay side panel. This location may impose operational venting constraints on Tug during ascent, which are undesirable. A remote hydrogen vent located in the tip of the Orbiter vertical stabilizer is recommended for Tug use.

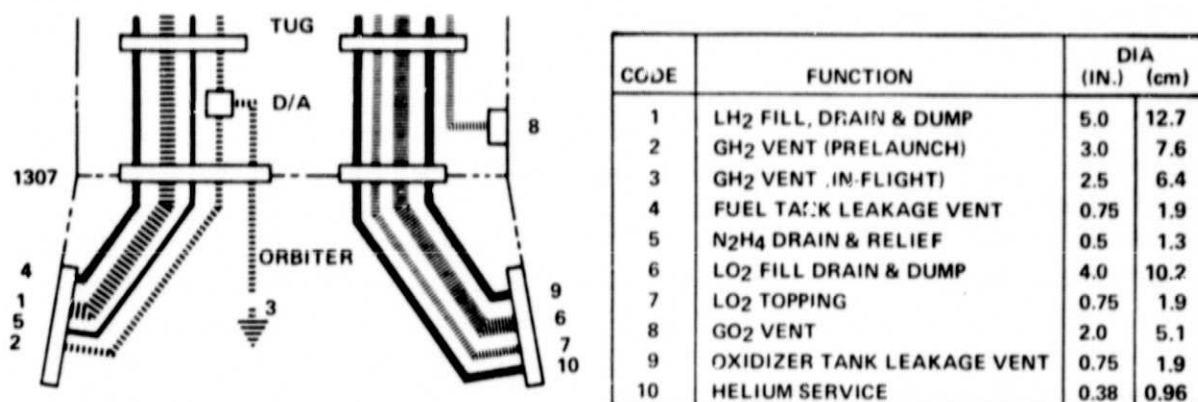


Figure 5-8. Baseline Tug/Orbiter Fluid Service Accommodations

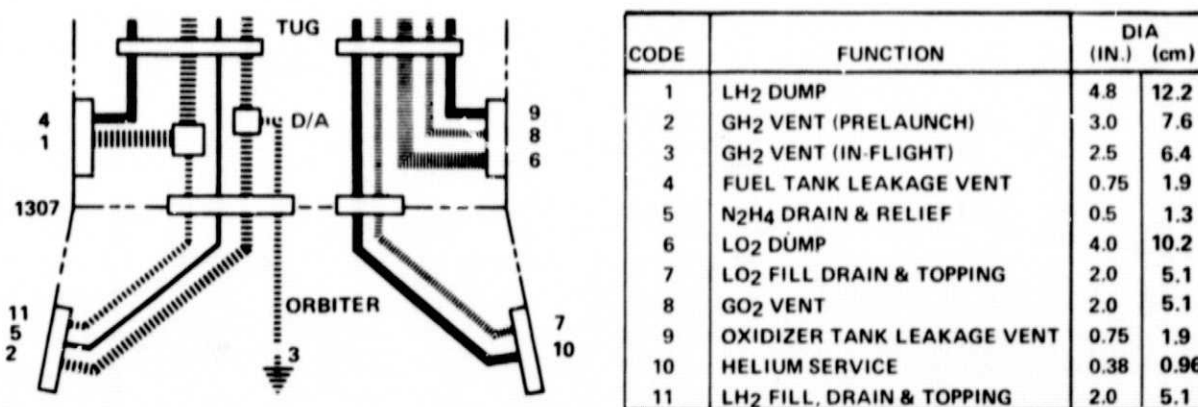


Figure 5-9. Optional Tug/Orbiter Fluid Service Accommodations

Space Tug/Orbiter fluid interfaces and operational requirements were defined that are compatible with all Orbiter abort requirements. The return to launch site (RTLS) abort depicted in Figure 5-10 is the propellant dump line configuration design driver. Dump line diameter requirements are predicated on simultaneous dump of both propellants at thrust-to-weight ratios between 1.0 and 3.0 during Space Shuttle main engine (SSME) operation. Minimum dump time available before SSME burnout (last RTLS opportunity) is 300 seconds, with SSME burnout occurring at an altitude of 170,000 feet (52 km), well above the 110,000-foot (34 km) altitude below which H_2 combustion is possible. At these altitudes, the dumped propellant plume has a two-phase (solid/gas) core 60 degrees wide surrounded by expanded gas out to the Mach infinity line, so no liquid or solid propellant impinges on the Shuttle.

With the dump system sized for the RTLS abort, propellant dump time for on-orbit abort extends to 1100 seconds because the lower Shuttle thrust-to-weight (T/W) ratio attainable reduces head pressure available in the LO_2 dump lines. This required on-orbit dump time is longer than the Orbiter RCS and/or OMS thrusting time normally available, so use of thrust produced by the dumped propellants (360 lb (1600 N) maximum) for settling must be employed during part of the dump. The Orbiter must provide axially aligned propellant dump exits in its Tug umbilical panel to avail itself of this capability. To initially establish stable dump flow and to reduce end-of-dump residuals, four Orbiter RCS thrusters are operated during the first 20 and the last 50 seconds of dump to increase settling T/W. Figure 5-11 shows end-of-dump residuals for the range of on-orbit T/W available. Calculated residuals using Tug propellant dump thrust settling only are very high and very sensitive to the actual dump thrust available. Use of four Orbiter RCS thrusters reduces residuals to near the practicable minimum and is recommended for the Tug on-orbit dump procedure. The results of these investigations have shown that dump of Tug's hydrogen and oxygen propellants is feasible and safe for all Shuttle abort modes.

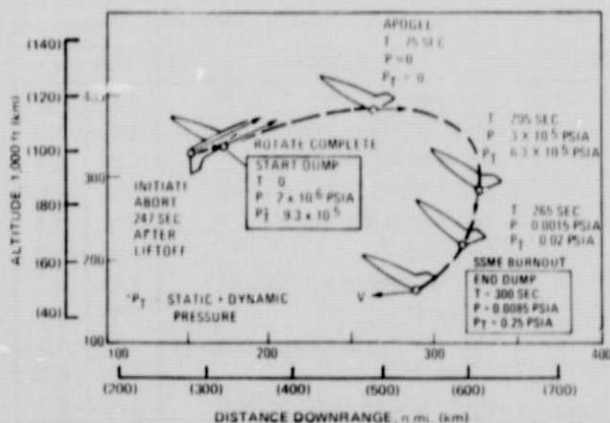


Figure 5-10. Tug Propellant Dump Parameters for RTLS Abort Trajectory

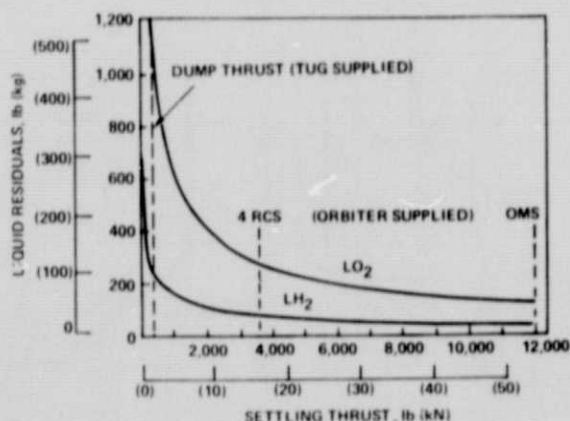


Figure 5-11. On-Orbit Abort Settling Thrust Effect on Tug Propellant Residuals

5.2.4 ENVIRONMENTAL SUBSYSTEM. The Tug and its payload must be capable of surviving in the environment of the payload bay; conversely, the Tug must not produce an environmental condition that can adversely affect the Orbiter or payload. This subtask assessed the environmental interface using the NASA-supplied baseline Tug and payload environmental requirements. Thermal, contamination, and acoustic environments were considered and the results of these investigations are summarized in Table 5-4.

The trade study conducted to establish compatible ground conditioning specifications and Orbiter payload bay conditioning control requirements for baseline Tug plus payload was the most important investigation involving the functional environmental interface. As the first step in developing prelaunch conditioning needs, spacecraft requirements were reviewed to determine the parametric constraints to be used in purge gas thermal analyses for Tug conditioning during prelaunch tanking. Temperature and humidity limit requirements were determined from the NASA/MSFC SSPDA document published in July 1974, for the fifty Space Tug payloads. Temperature limit data showed a common max/min temperature limit band between 59F and 69F (288K and 294K), with a maximum relative humidity requirement of 0 percent for some spacecraft and values up to 95 percent for others. No minimum limits were given; i.e., 0 percent relative humidity is apparently acceptable for all spacecraft.

Table 5-4. Summary of Environmental Interface Work

Investigation	Results	Recommendations
SSPD Spacecraft Prelaunch Thermal Environment	Limits between 59 and 69F (288 and 294K) acceptable for all SSPD Tug payloads.	Use prelaunch purge temperature of $64 \pm 5F$. (291 \pm 3K)
Prelaunch Conditioning	Orbiter purge temperature, humidity and flow capability acceptable for Tug prelaunch operation.	Minimum humidity and maximum flow best for prelaunch.
Tug Attachment Fitting Temperature Extremes	No design impact caused by temperature extremes.	No fitting design changes necessary.
MLI Purge Vent Location	No spacecraft contamination with payload bay vent.	Vent MLI helium purge gas to payload bay.
Ground Operations Cleanliness Requirement	Class 10000 environment acceptable for 92% of Tug spacecraft.	Use class 10000 purge for facilities, GSE and payload bay.
Flight Operations Contamination Control	APS exhaust impingement can be major contamination source.	Inhibit Tug APS activation until clear of Orbiter.
SSPD Tug Payload Acoustic Environment	64% of SSPD Tug payloads appear to be acoustically sensitive.	SSPD Tug payloads require detailed compatibility study

To preclude condensation of moisture on payload bay and Tug surfaces when Tug cryogenic propellants are tanked, payload bay purge nitrogen is required with a dewpoint below that of anticipated surface temperatures. Parametric analyses were performed to predict purge gas and Tug surface temperatures as functions of GN_2 flow rate and inlet temperature. The Orbiter cargo bay prelaunch conditioning system depicted in Figure 5-12 provides purge gas flow from a forward manifold past the spacecraft and Tug and through check valves at the Station 1307 bulkhead (≤ 115 lb (52 kg) per minute) and the Station 1128 payload bay vent (> 115 lb (52 kg) per minute). Three stub outlets are available in the purge distribution duct for special conditioning flow requirements.

As shown in Figure 5-13 a purge rate of 120 to 140 lb (54 to 64 kg) per minute is required for purge nitrogen having a dewpoint of -76°F (213K) to remain within the payload temperature requirements. For gas with a -45°F (231K) dewpoint, 230 to 280 lb (104 to 127 kg) per minute flow is required, and for gas with a dewpoint as high as -32°F (238K), the flow rate requirements is beyond the present Orbiter capability of 364 lb (165 kg) per minute. Relative humidity for purge gas with dewpoints such as these is, for all intents, 0 percent. Condensation and frost formation will result if purge gas with anything over a fractional part of 1 percent relative humidity is used with Tug. This investigation showed that the Orbiter-supplied prelaunch conditioning system is compatible with the Tug plus Tug payload requirements. Since a forward-to-aft purge flow is desirable over the full Tug length, biased aft cargo bay side vents are needed to exhaust GN_2 purge flow exceeding the 1307 bulkhead check valve capability.

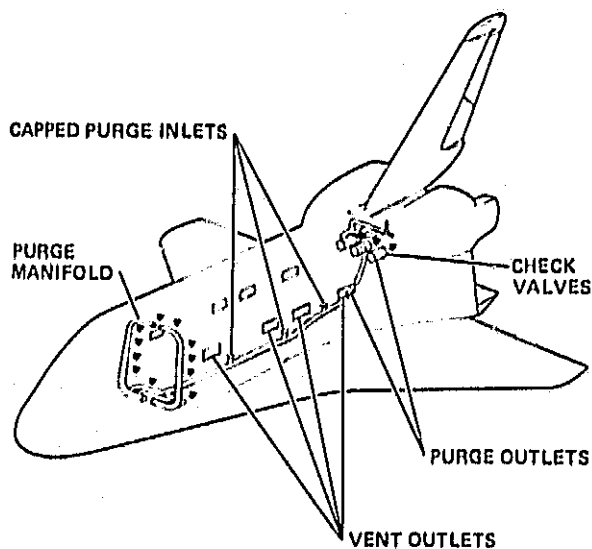


Figure 5-12. Orbiter Prelaunch Conditioning Provisions

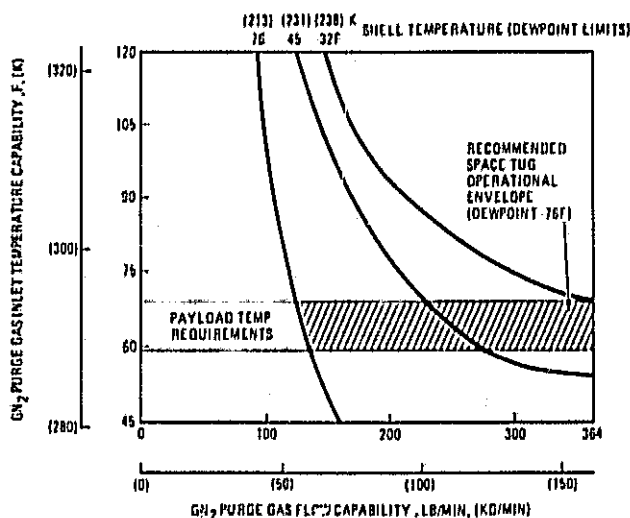


Figure 5-13. Tug Plus Payload Purge Requirements

5.2.5 AVIONICS SUBSYSTEM. Avionics interfaces between Tug and its operating environment are of both a functional and physical nature and consist of 1) hardwired interfaces between the Tug vehicle, its deployment adapter, the Orbiter, ground, and the Tug payload; and 2) RF communication links interfacing the Tug with Orbiter and ground equipment when the Tug is deployed from the Orbiter.

11

4

iv

Table 5-5. Summary of Avionics Interface Work

Investigation	Results	Recommendations
Allocation of Tug/Orbiter Interface Hardware + Software	Three Tug-supplied control panels: ABORT, DEPLOYMENT, CHECKOUT INITIALIZATION. Tug-supplied software ≈ 10 k. Orbiter-supplied equipment: GPC + S/W operating systems, MDM, PSP, PI, MTU, PDI.	Reduce physical interface through multiplexing; hard lines for safety monitors. Use Orbiter-supplied P/L support equipment where possible. Use Tug capability to reduce Orbiter software requirements.
Effectivity/Man-Machine Interface	Three-man crew adequate for Tug. Mission Specialist (Tug control). Pilot (deployment/capture). Commander (vehicle control).	Tug controls at MSS. Deployment controls at PHS. Use of CRT and keyboard with computer control, monitor.
Tug/Payload Power Requirements	Orbiter-supplied power (1000W) not adequate during ascent and abort for Tug + D/A + P/L. (1478 W required.)	<div style="display: flex; align-items: center;"> Tug plus payload { 695 panel power for pre-launch. Tug fuel cells during flight. </div> <div style="display: flex; align-items: center;"> D/A { 1307 panel power all mission phases. </div>
Service Panel Locations	Cargo bay panels and raceway size provisions adequate.	Provide power return provisions at LMA 1307, 695. Provide cable connector backshell grounding provision at all service panel locations.
	No Tug or Tug/payload requirement for T-4 panel.	Delete T-4 panel.

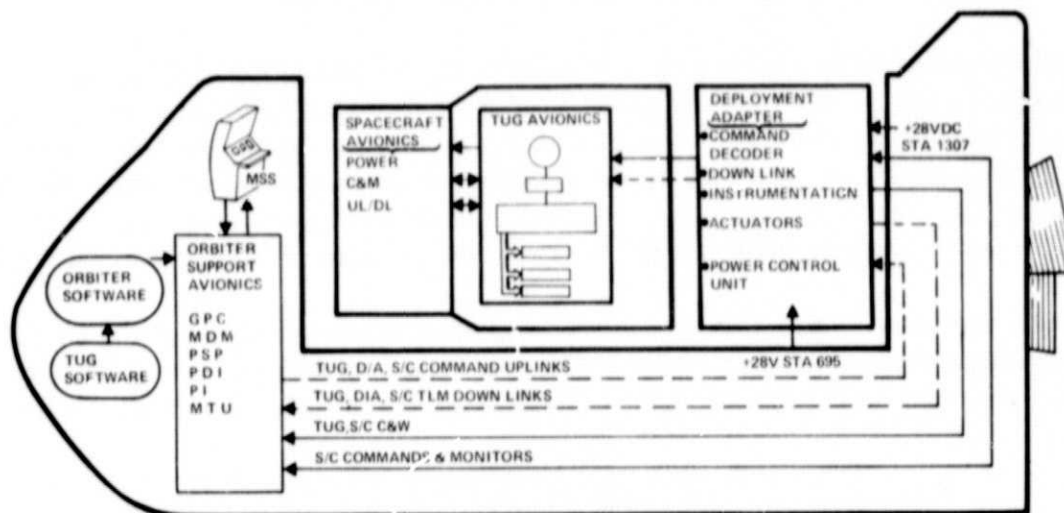


Figure 5-14. Diagram of Recommended Tug Avionics Interface

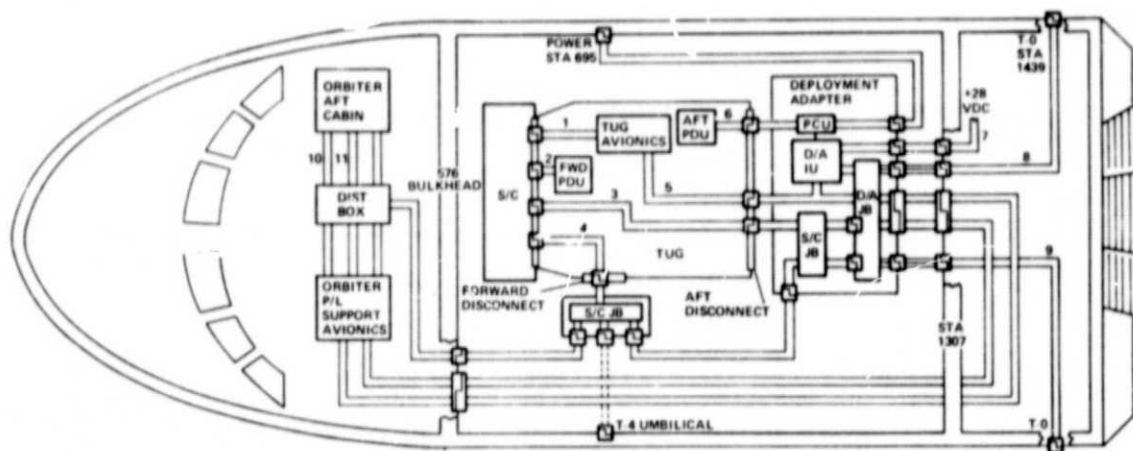
Data Interleaver (for payload operational telemetry (TLM); payload Caution and Warning (C&W) electronics unit and indicator units; and limited use of the Orbiter general purpose computers.

Tug use of the Orbiter avionics is assumed in addition to Orbiter supplied cathode-ray tube (CRT) and keyboards, and associated alphanumeric display electronics and mass memory storage for Tug-unique software. Tug-provided equipment required in the aft crew area includes Tug operations control and abort control panels plus the associated interface electronics. Discrete inputs to the P/L MDM from the mission specialist station (MSS) control panels are used to initiate GPC activity for Tug control under normal and anomalous conditions. Discrete outputs to the MSS control panels from the P/L MDM provide talk-back monitoring of events to the Mission Specialist. Safing of Tug system functions is accomplished through redundant serial links from the payload signal processor units (2) to the D/A interface unit and Tug avionics.

Optimum use of Orbiter-provided capability was made to 1) reduce the Tug design and development costs by not duplicating Orbiter payload support functions, and 2) simplify Orbiter/Tug operations on the ground and inflight. Less Tug-unique equipment and interfaces installed into the Orbiter should aid turnaround time and assist interface test and checkout; during inflight operations crew familiarity with standard Orbiter hardware should ease crew operation associated with Tug.

The electrical service routing requirements for the spacecraft, Tug, Deployment Adapter, and Orbiter are shown in Figure 5-15. The various Tug and spacecraft interface functions are grouped according to function and identified by code number.

Power is supplied to the Tug/spacecraft and the Deployment Adapter through separate interfaces (Codes 6 and 7, respectively). Orbiter-dedicated and backup power from



UMBILICAL DETAILS

CODE	FUNCTION	FROM	TO
1	S/C UL CONTROL/MONITOR	S/C	TUG
2	S/C POWER	TUG	S/C
3	S/C DL C&W SAFETY	S/C	ORBITER
4	S/C C/O PRELAUNCH	S/C	ORB/LPS
5	TUG D/A, UL, DL, C&W, TIME	TUG D/A	ORBITER
6	TUG S/C POWER	ORBITER	TUG
7	D/A POWER	ORBITER	D/A
8	TUG S/C, UL, DL, DATA	TUG S/C	LPS
9	TUG S/C, UL, DL, DATA	TUG S/C	LPS
10	TUG AFT CABIN WIRING	MSS	DIST/MDM
11	S/C AFT CABIN WIRING	PSS	DIST/MDM

Figure 5-15. Tug Electrical Services Routing

station 695 is available to the Tug via the Deployment Adapter power control unit (PCU) for on orbit-checkout and validation operations, while Deployment Adapter power (dedicated and backup) is provided through Orbiter station 1307.

The combined Tug plus payload service wiring requirements obtained from this recommended routing plan are well within stated Orbiter capability. Table 5-6 compares Orbiter accommodations with Tug and payload requirements.

5.2.6 INTERFACE SAFETY. The safety analysis objective was to identify and eliminate or control any interface hazard that can compromise safety of the Orbiter, Orbiter crew, or ground crew. The fault-tree analyses previously developed during the Space Tug Systems Study was used to ensure that safety analyses are conducted within the framework of overall Shuttle safety. Evolving interface designs were evaluated to ensure that the safety requirements were properly implemented in the candidate interface designs. As each design neared completion, a safety criteria checklist was prepared to document compliance or highlight any safety criteria deviations, and the rationale for these deviations.

A mission hazard analysis was conducted to 1) identify potential hazards associated with Tug/Shuttle interfaces and 2) identify suitable design features, procedures, and operational constraints that eliminate or control identified hazards. Operations associated with potential emergency situations were examined, as were interface

Table 5-6. Orbiter Accommodation/Tug+Payload Requirements Comparison

Service	Orbiter Provision	Tug Requirement	Payload Requirement
Connectors	207 TSP	16 TSP	121 TSP
Aft Crew Station (Sta 576)	98 TP 29 Coax 6 Cable B		3 Coax
Connectors	202 TSP	6 TSP	15 TSP
T-O Umbilical	14 Coax	2 Coax	24 TP
Power			
MSS	350 W	100 W	600 W
Sta 695	1000 W	1740 W	
Sta 1307	500 W	(Zero during ascent) 781 W (D/A only)	

hazards related to normal Tug operations. Included in this group are hazards associated with propellant dumping during launch or flight aborts, potential propellant leaks into the payload bay, potential overpressurization of propellant tanks, emergency release of Tug/Adapter through extra vehicular activity (EVA), and potential Tug/Orbiter collision.

The principal tool used in assessing reliability of interface designs was the failure modes and effects analysis (FMEA). Single failure point information was developed for failures that might result in mission loss and those that could compromise the safety of Orbiter/crew. Mission-loss single failure points were considered acceptable as long as the overall reliability requirement was attained. Safety-critical single failure points were "designed out," or alternative modes of operation and backup capability developed to preclude them.

The summarized results of the interface safety investigations are itemized in Table 5-7. Of the many analyses conducted, caution and warning was of particular interest.

The philosophy used in the caution and warning (C&W) system is that caution and warning indication should be used only when a threat to the safety of the Orbiter or crew manifests itself and immediate crew action is required. Implicit in this philosophy is the requirement that the crew must have available to them some action that will counteract the hazard. The implementation approach used in this analysis is shown in Figure 5-16. The caution and warning functions for the Tug were identified through review of the failure modes and effects analysis and hazard analyses.

A warning is defined as an event that requires immediate crew action/attention. Warnings result in 1) illumination of the master warning light, 2) illumination of a specific warning light, 3) continuous sounding of the warning horn, and 4) a CRT display indicating the warning condition and the crew action to be taken. The master warning light and the warning horn can be reset to OFF, but the specific warning light and the CRT display will remain active until the hazardous condition is actually cleared.

Table 5-7. Summary of Interface Safety Work

Investigation	Results	Recommendations
Conflicting Payload (Tug) Safety Requirements	Severe design complexity and high cost for "Fail Operational Fail Safe" criteria.	Use: No single failure shall result in a hazard that jeopardizes the flight or ground crew.
Caution and Warning Requirements	Identified caution vs warning items; developed test and display parameters.	5 tank pressure high and low warning functions. 1 master caution function 14 cautions on CRT
Special Tug Configuration Hazards:		LCM on both propellant tanks. Encapsulated umbilical disc. Overboard purge vent. Employ arm-safe switches. Employ isolation valves.
Propellant Leakage Pressurization System Inadvertent Operation of Flight Systems	Identified Tug detail design parameters for MSFC consideration.	
Special Tug Operational Hazards:		
Deployment/Retrieval	Potential comm deadband.	C&W hardwired through rotation. C&W via RF after separation.
Abort (Propellant Dump)	Burnable mixture cannot be ingested by Orbiter.	Concurrent dump safe above 170,000 ft (52 km) altitude.
Contingencies	Possible mechanism failures.	Use RMS with EVA backup.
Propellant Horizontal Vent/Drain	Operational convenience to accommodate double failure - not a safety requirement.	No horizontal drain lines. Provide horizontal hydrogen vent.

A typical example of a warning CRT display and the information that might be suitable for display is shown in Figure 5-17. A three-color presentation (red, yellow, green) is recommended to highlight critical information and aid in rapid crew evaluation and response. Five Tug functions, all associated with propellant tank pressures, have been identified as warning indications; these are

LH₂ TANK OVERPRESSURE, LO₂ TANK OVERPRESSURE, LH₂ TANK UNDERPRESSURE,
LO₂ TANK UNDERPRESSURE, N₂H₄ TANK OVERPRESSURE

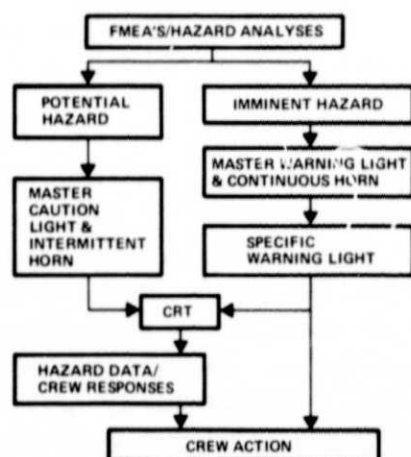


Figure 5-16. Caution and Warning Implementation

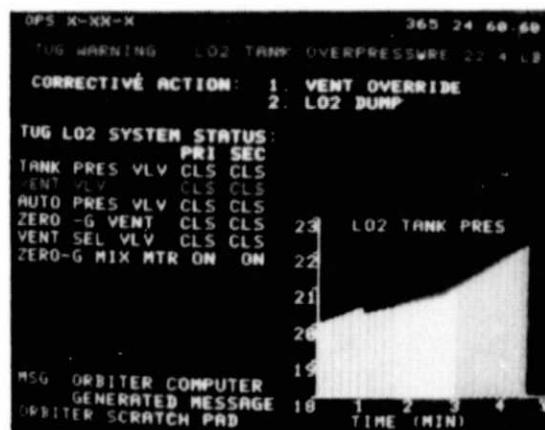


Figure 5-17. Typical CRT Warning Display with Problem Solving Information

Each of these functions is displayed on the MSS caution and warning panel to provide immediate crew problem identification.

A caution is defined as an event that does not constitute an immediate hazard, but does require corrective crew action before a secondary event (or failure) occurs. Cautions result in 1) illumination of the master caution light, 2) intermittent sounding of the warning horn, and 3) an indication on the CRT of the caution condition and the crew action to be taken. The master caution light and the warning horn can be reset to OFF, but the CRT display will remain active until the potential hazardous condition is cleared.

Fourteen caution indications have been identified for Tug and its peripheral equipment:

APS ISO VLV OPEN	DEPLOY ARM/SAFE ARMED
ME ISO VLV OPEN	APS CLUSTER FAILED
TUG/ADAPTER LATCH OPEN	APS PRI ELEC FAILED
TUG/SUPPORT LATCH OPEN	APS PROP LOW
TUG/ORB DISC OPEN	H ₂ IN LCM
ME ARM/SAFE ARMED	H ₂ IN P/L BAY
APS ARM/SAFE ARMED	N ₂ H ₄ IN P/L BAY

5.2.7 PAYLOAD ORBITER SERVICE ACCOMMODATIONS TRADE. Because Tug payloads compete with the Tug for Orbiter-supplied services such as power and data processing, an early study task was analysis and identification of the accommodations/support services required by Tug payloads and the determination of their safety requirements.

Once the service requirements were defined using SSPD data, analyses were made to determine the best method of accommodating these services. Figure 5-18 shows the four possible implementation techniques.

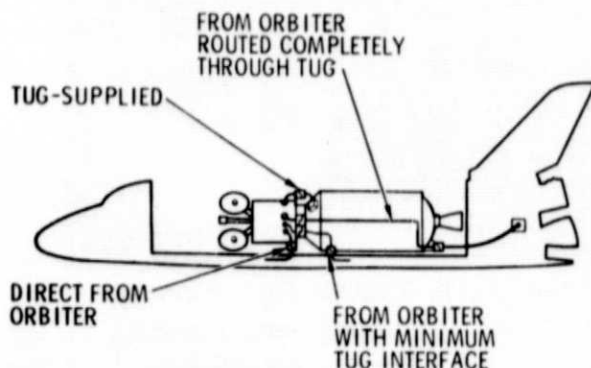


Figure 5-18. Payload Services Accommodating Choices

The results of the payload services accommodations trade are graphically displayed in Figure 5-19 and shown in greater detail in Table 5-8. Power and caution and warning signals are routed through (or supplied by) Tug, while fluid services are generally routed direct to the Orbiter through a forward-mounted Tug umbilical panel. The Tug-mounted forward panel was selected to standardize this interface, since direct Orbiter-to-payload umbilicals would be nonstandard due to payload geometry variations.

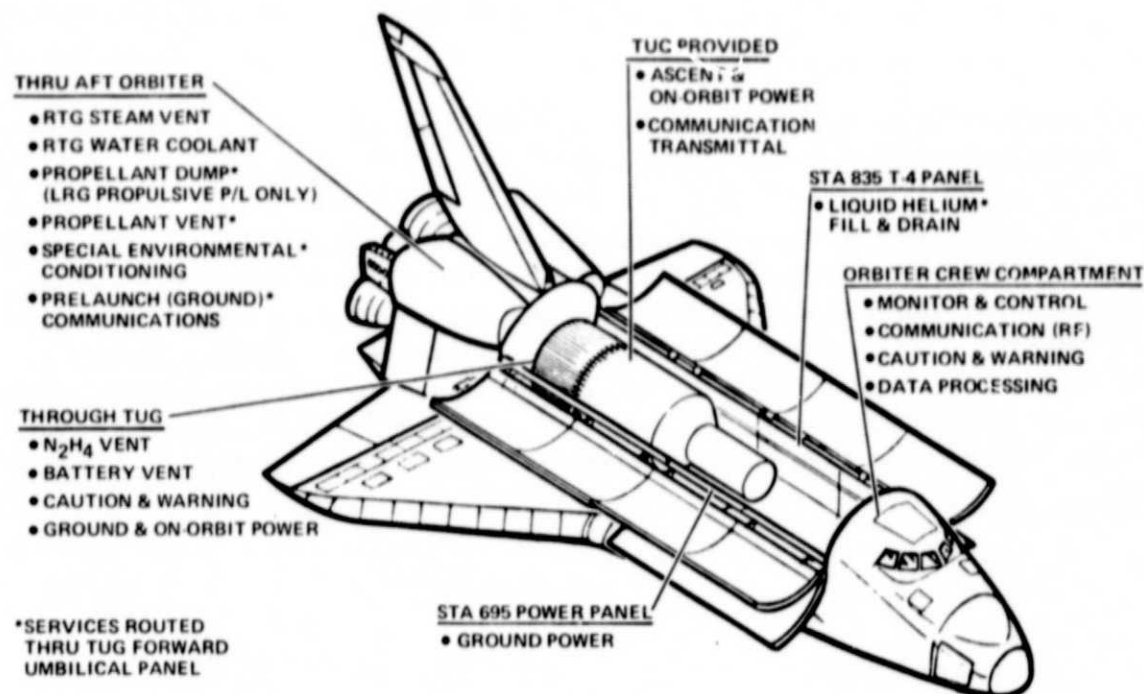


Figure 5-19. Recommended Services Implementation

Table 5-8. Payload Service Accommodations

Payload Function	Service Level	Accommodation	Interface	
			Tug	Orbiter
Prop. F&D	~ .5 in. dia. each prop.	Remote	No	No
Abort Dump	< 500 lb	Self contain	No	No
	>> 500 lb	Overboard dump kit	No*	Yes
Vent	~ .5 in. dia N ₂ H ₄ prop.	Integrate w/Tug RCS vent	Yes	Existing
	~ .5 in. dia each other prop.	Overboard vent kit	No*	Yes
Press Fill	~ .25 in. dia	Remote	No	No
Vent	~ .25 in. dia	Into cargo bay	No	No
Battery Vent	~ .5 in. dia	Integrate w/Tug bat. vent or self contain	Yes	Existing
LHe F&D	~ 1.0 dia	Direct to 835 T-4 panel	No*	Yes
Vent	~ 1.0 dia	Into cargo bay	No	No
RTG Cooling	~ .5 in. dia H ₂ O inlet/outlet	Thermal control unit (water boiler) kit	No	Yes
	~ 3.0 in. dia steam vent		No	Yes
Shroud Repress	No known	Payload autonomous	No	No
Conditioning	~ 3.0 in. dia class < 5000 GN ₂	Direct to Orbiter	No*	Yes
Communication	2 KBS up 51 KBS down	Via Tug avionics	Yes	Yes
Caution & Warning	35 signals	Through Tug	Yes	Yes
Data Processing	Storage & Computation	Orbiter supplied	No	Yes
Power	700 W ground & on-orbit	Orbiter 695 panel via Tug	Yes	Yes
	600 W ascent	From Tug fuel cell	Yes	No

*Assumes forward umbilical panel

To standardize Orbiter interfaces while maintaining desired payload mix flexibility, it is recommended that provisions for umbilical panels be located at multiple Orbiter fuselage stations. Figure 5-20 shows an example of panels located at $Y_O = -30$ and $X_O = +10$ in. from each of nine centermost primary attachment locations. The panels will enable disconnection of payload fluid and electrical services for deployment and reconnection following retrieval. Only the panels required for a particular mission will be installed. The umbilical panels will be connected to the bulkhead service panels, T-4 panel, or 695 power panel through tubing and harness kits routed through the cargo bay service raceways. The proposed location for these mission kit umbilical panels has been selected to preclude harness violation of Orbiter mid-fuselage crawlway space.

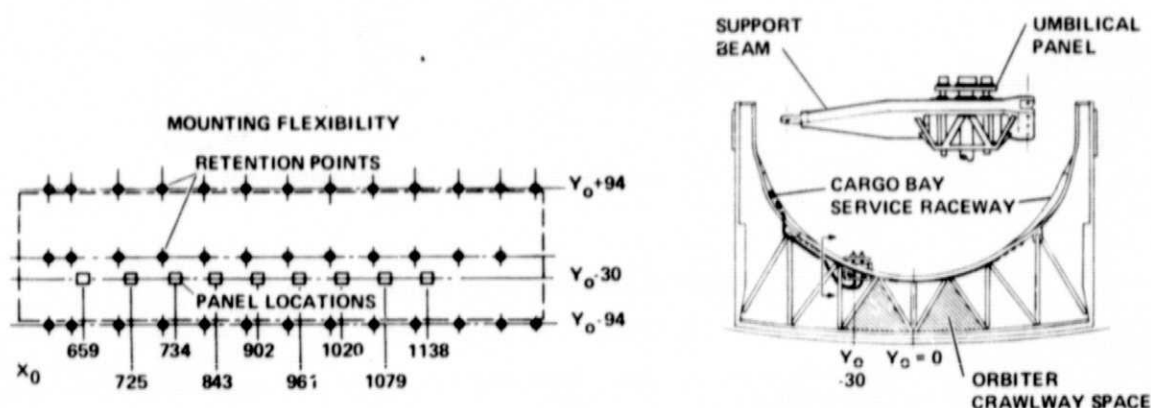


Figure 5-20. Typical Panel Configuration and Suggested Mounting Locations




Incorporation of this capability would permit satisfying limited use requirements without penalizing Tug design by carrying special lines on all flights. If standardized umbilicals are not provided, each payload may require several different umbilical designs with the resulting Orbiter changes. The incorporation of this service accommodation throughout the Orbiter cargo bay is strongly recommended.

5.3 TUG/ORBITER INTERFACE REQUIREMENTS

This task assessed the baseline Tug subsystem interface recommendations of the Subsystem Interface analyses from a total Tug/Orbiter standpoint, identified the recommended composite Tug/payload interface requirements, provided a detailed definition of these requirements and proposed changes to the Space Shuttle System Payload Accommodations document JSC 07700, Vol. XIV Rev C.

The initial interface requirements task activity, an interface system trade study, provided a comparative assessment of three alternative support/deployment methods. Table 5-9 and the discussion below summarize the considerations and results of this assessment.

Table 5-9. System Assessment of Tug/Orbiter Support/Deployment Methods

EVALUATION PARAMETER	ADAPTER 	LATERAL ROLLOUT 	ROTATE W/RMS 
DEPLOYMENT DEVICE	D/A - RMS	PIVOT ARMS - RMS	RMS
CLEARANCE CONTROL	VERY GOOD	BEST	MARGINAL
C&W FUNCTIONS	NO DEADBAND	DEADBAND	DEADBAND
UMBILICAL ALIGNMENT	BEST	ADEQUATE	ADEQUATE
OPERATIONAL SIMPLICITY	VERY GOOD	ADEQUATE	POOR
TUG PERFORMANCE	REFERENCE	-48 LB (-22 kg)	+113 LB (+51 kg)
I/F EQUIP COST	REFERENCE	-\$0.09M	-\$0.76M
RECOMMENDATION	SELECTED		

The adapter and pivot arm deployment/alignment techniques provide the best Tug/Orbiter clearance control. Additionally, the adapter provides a positive guard against structural interference of the Tug engine and aft cargo bay bulkhead during retrieval operations when Tug is RMS inserted back into the Orbiter. The deployment adapter concept eliminates the gap in communication of safety monitor data. Hardwires are maintained through rotation until RF communication can be established. The close coupling of Tug and adapter provide better umbilical alignment than floating Tug-to-Orbiter connections.

Operationally, the rotating deployment adapter provides Tug system autonomy, ease of maintenance and checkout, simplifies Tug changeout, and improves interface verification by enabling a complete system checkout of in-flight functioning umbilicals before installation in the cargo bay. A small geosynchronous delivery performance difference exists for the three concepts. The cost differences are also insignificant.

The result of the deployment/support system trade was the recommended retention of a deployment adapter concept very similar to that used with the MSFC baseline Tug. The overriding selection criteria were operational flexibility and safety rather than performance or cost considerations.

Based on the deployment adapter system selection for Tug/Orbiter interfacing, detailed description of the Tug-peculiar peripheral equipment was accomplished. In addition to the cylindrical D/A structure, peripheral equipment includes monitor and control panels and software, mechanisms, umbilical panels, and fluid/electrical umbilical kits.

Tug peripheral equipment can generally be separated into the three categories shown in Figure 5-21: payload bay support equipment (deployment adapter), crew compartment equipment, and umbilical kits that connect Tug plus deployment adapter to ground umbilicals and Orbiter crew controls.

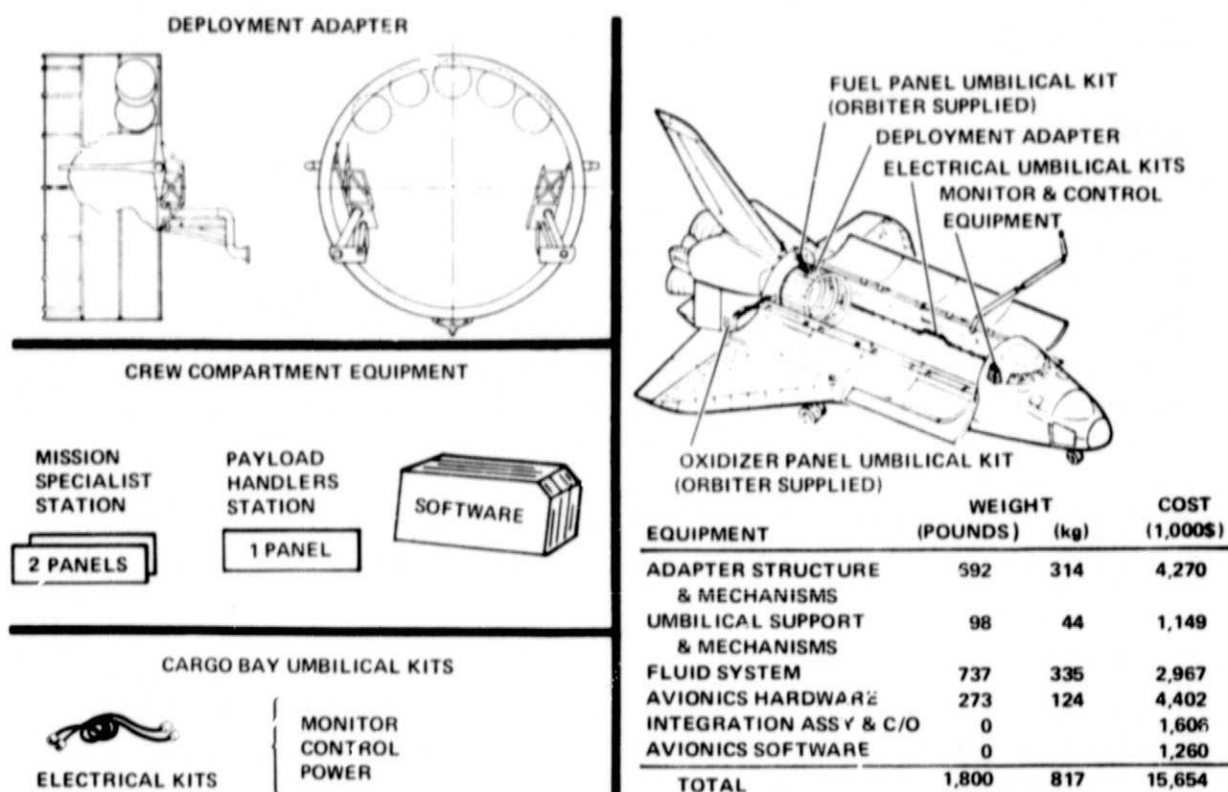


Figure 5-21. Tug/Orbiter Peripheral Equipment Description

Deployment Adapter. The adapter consists of a load-carrying cylinder that provides deployment positioning and contains subsystem interface equipment, including the abort helium storage bottles, umbilical panels and interface electronics.

Crew Compartment Equipment. The Tug uses Orbiter-supplied man-machine interface monitor and control equipment located in the crew compartment, data processor, memory storage, and the pilot and commander's CWA panels. The Tug-supplied equipment needed to use this Orbiter-supplied equipment includes two display/control panels for the MSS and one for the payload handler station, plus integration software.

Cargo Bay Umbilical Kits. Tug fluid kits are included in the deployment adapter. The only separate kits are those for monitor and control electrical wiring, Tug power, and the forward umbilical panel disconnect mechanism and lines.

Tug/Shuttle interface equipment DDT&E cost at WBS Levels 5 and 6 is \$15.6M. This cost reflects total cost expended to the government for all phases of Tug/Shuttle interface planning, liaison development and integration, with estimated cost growth allowances for uncertainties. Interface equipment production cost is estimated at \$2.7M per shipset.

Orbiter envisioned payload accommodations are generally compatible with the recommended Tug/Orbiter operational plan and its associated interface requirements. An evaluation of documented Orbiter payload services (JSC 07700, Vol. XIV, Rev. C) indicated that some changes would be desirable for Tug plus its payloads. Twenty-two proposed change requests were prepared by the Space Tug/Shuttle Interface Compatibility Study Team and submitted to MSFC for their assessment and processing. Some of those changes were revised several times to reflect interface requirements revisions and MSFC directed modifications.

Orbiter accommodations changes submitted are itemized in Table 5-10. Most of these proposed changes clarify or better describe Orbiter accommodations already identified in JSC 07700 Vol. XIV. Several of the avionics change requests (012, 014, 017 and 022) asked for expanded payload use of Orbiter-supplied equipment. Proposed changes prepared by the interface compatibility study were transmitted to MSFC as the first step in the review/implementation cycle.

Table 5-10. Interface Study Proposed Orbiter Accommodations Changes

Ident	Title	Effect on Orbiter Accommodations	Interface Area Technical Discipline
001	GN ₂ Purge Requirements	Aft vent provisions	Environmental
002	T-0 Fuel Panel Services	Detail description	Fluid/electrical
003	T-0 Oxidizer Panel Services	Detail description	Fluid/electrical
004	Keel FTG Rotation Mod	New deployment requirement	Structural
005	RMS End Effector	Detail requirements	Mechanical
006	RMS Control Requirements	Detail description	Mechanical
007	Orbiter C&W Requirements	P/L use	Safety
008	Prop Orientation Requirements	Settling thrust	Fluids
009	Fwd BHD Services	Detail description	Electrical
010	Aft BHD Services	Detail description	Electrical
011	Vent & Dump Requirements	Exhaust Provision	Fluids
012	Data Bus Access	Expanded P/L use	Avionics
013	Expanded C&W Cap	More capability	Avionics
014	Expanded PSP Cap	Expanded P/L use	Avionics
015	1307 Panel Relocate	Grnd OPS requirement	Fluid/electrical
016	Fwd Umbilical Panel	Flexible services	Fluids
017	Command Cap Requirements	Expanded P/L use	Avionics
018	TLM Input Requirements No. 1	Detail description	Avionics
019	Struct Support Clarif	Clarification	Structural
020	New Bridge Beam	New requirement	Structural
021	TLM Input Requirements No. 2	Detail description	Avionics
022	Crew Cabin I/F	Expanded P/L use	Avionics

SECTION 6

STUDY LIMITATIONS

Interface compatibility study limitations are associated with each of the major elements considered (Tug, tug payloads, and Orbiter) in both a hardware and operational sense. Each of these elements exhibits definition uncertainties, which are dependent on their development phase.

6.1 SPACE TUG

The Tug design is still in a conceptual phase. While its basic geometry, main propulsion, and other major subsystems are relatively well defined, the possibility of significant future changes should not be ignored. Recommendations by the interface study and the other parallel contracted activities have had significant interface impacts. For example, the recommended use of thermally integrated lightweight fuel cells eliminates supercritical reactant fill, drain and vent lines, which simplifies the fluids interface considerably. Future changes of this type should constitute expected results from subsequent studies and technology advancements. While subsystem changes will affect individual service requirements, no Tug modifications are envisioned that would negate the basic interface approach recommended by the interface study.

This approach employs a flexible intermediate unit (the deployment adapter), which adapts Tug to Orbiter and eliminates or appropriately conditions interface impacts.

6.2 TUG PAYLOADS

Most Shuttle-era Tug payloads, while based on currently designed spacecraft, are in a conceptual definition phase. Many payload agencies have retained a "We plan to do business with Shuttle just as we now do with expendable launch vehicles" attitude, which does not appear to fully recognize (or take advantage of) Shuttle differences. Once Shuttle becomes operational, these payloads will adapt themselves to exploit Shuttle's peculiar (with respect to expendable launch vehicles) benefits. Changes in desired payload services and operations that affect both Tug and Orbiter will result.

6.3 SHUTTLE ORBITER

Orbiter development had proceeded to manufacture of the horizontal flight test article during the interface study performance period. Although the basic Orbiter vehicle hardware was in fabrication, payload interface accommodations and services were planned, rather than implemented. Payload accommodations change activity is expected to continue at its current level for at least the next two years, resulting in considerable revision to currently planned services.

SECTION 7

IMPLICATIONS FOR RESEARCH

Interface-related areas that would benefit from additional technical effort have been identified during performance of the Space Tug/Shuttle interface compatibility study. These technical activities have been separated into four categories: identification of technology drivers, additional analyses of critical interface areas, predevelopment breadboard or prototype design activity to reduce risk and program costs, and recommended supporting research and technology programs.

7.1 TECHNOLOGY DRIVERS

This category pertains to new technology developments required to effect the recommended interface concept. Since all study recommendations for Tug/Orbiter interface implementation use current technology and/or available off-the-shelf hardware, no technology drivers exist for peripheral equipment development.

7.2 TECHNICAL ANALYSES

Areas listed below are recommended for expanded interface analyses. All these areas were investigated during the interface compatibility study, and additional analyses beyond the scope of contracted study effort are required for problem solution or interface definition/verification. In conjunction with the needed analyses, many of these items are also candidates for subsequent predevelopment work as indicated in Section 7.3.

- a. Structural Dynamics. More rigorous analyses using up-to-date Orbiter data are required to better determine Orbiter payload effects.
- b. RMS Software Control. Quantification of RMS joint (wrist, elbow, shoulder) angle geometry and force characteristics for control software development.
- c. Tug Monitor and Control Software. Software requirements analysis of all Tug/Orbiter operational interfaces (status verification, deployment, retrieval, abort) including determination of Tug/Orbiter software interfaces and allocation of software responsibility.
- d. Tug Caution and Warning Software. Using philosophy and implementation tools developed during interface study investigations, software should be designed for all Tug caution and warning functions.
- e. Avionics Ground Interface with LPS. Tug/Orbiter interface avionics definition should be expanded to include its functional prelaunch ground interface with the KSC launch processing system.

7.3 PREDEVELOPMENT ACTIVITY

To demonstrate feasibility of the preceding technical analyses results, simulation activity with prototype software and hardware should be performed. This pre-development work will verify analytical solutions and/or identify interface problems early enough to reduce risk and program costs. Three areas have been identified that offer very fruitful ground for simulation-demonstration work.

- a. Remote Manipulation System (RMS) control for Tug deployment, recapture and insertion into the cargo bay.
- b. Prototype development and demonstration of Tug deployment adapter (D/A) mechanisms.
- c. Integration and test of Tug crew compartment monitor and control equipment with D/A peripheral equipment and selected Tug prototype systems and flight operations.

7.4 SUPPORTING RESEARCH AND TECHNOLOGY

Several interesting research areas associated with Tug/Orbiter interface needs were identified during the study. They include applications problems that must be resolved, pure theoretical research, and investigation of a current expanding technology for possible space application.

- a. Efficient method of concentrated load introduction into Tug and deployment adapter graphite epoxy structure.
- b. Development of graphite epoxy structure grounding technique to preclude static charge buildup and subsequent discharge to Tug tank structure and Orbiter.
- c. Use of a Centaur vehicle to conduct a high altitude LH_2 - LO_2 engine charging experiment.
- d. Development of low-power, high-reliability actuators for space Tug control of fluids and gases.
- e. Evaluation of optical data link techniques for possible Orbiter/Tug interface communication benefits in reduced weight and power requirements, increased electrical signal isolation, and higher operating speeds than conventional interface components.

SECTION 8

SUGGESTED ADDITIONAL EFFORT

Continued Tug/Orbiter interface-related activity should be pursued in areas of 1) Orbiter payload accommodation suitability for Tug, 2) updating of Tug definition to incorporate latest study recommendations, and 3) proposed analytical and pre-development work contained in Section 7.

During the performance period of the interface study, numerous changes in Orbiter payload interface accommodations and Orbiter flight/ground operations occurred, which affected Tug/Orbiter interface implementation concepts and Tug conceptual design. These Orbiter changes will continue throughout Shuttle development and flight test as Orbiter performance limitations, funding constraints, and general payload accommodation requirements become better known. Tug evaluation and reaction to this on-going Orbiter change process must be continued to assure the final interface compatibility of these two vehicles. Processing of additional Orbiter accommodations changes against JSC 07700 Vol. XIV should be continued to assure future Tug/Orbiter interface compatibility.

The interface study and parallel MSFC-sponsored operations, payloads, and avionics studies have all recommended baseline Tug design, operations, and interface implementation revisions. Convair's combined interface compatibility study and Tug avionics study team, consisting of experienced Space Tug system study personnel, is uniquely qualified to aid MSFC in updating their baseline Tug configuration and supporting documentation. Data is now available to better definitize Tug subsystems and their integration. For example, a current Tug structural model, incorporating support recommendations from the interface study, should be developed for Shuttle integration analyses.

Recommended Tug and peripheral equipment avionics systems should be integrated into the baseline Tug configuration. In addition to Tug design and configuration revisions, associated changes should be incorporated into the MSFC 68M00039 baseline Tug documentation.

The technical analyses and predevelopment activity delineated in Section 7, Implications for Research, should be initiated immediately to verify recommended interface solutions and identify potential problems. Early performance of these tasks will alleviate critical downstream cost impacts and reduce overall program risk.